A Study to Evaluate Latent Mortality Associated with Passage through Snake River Dams: 2008 Tagging Activities and Final Report for the 2005 Study Year

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EXECUTIVE SUMMARY

During spring 2008, the National Marine Fisheries Service PIT-tagged yearling hatchery Chinook salmon *Oncorhynchus tshawytscha* for the fourth year of a study to evaluate latent mortality associated with passage through Snake River Dams. We also monitored adult returns from study fish tagged in 2005, 2006, and 2007. Returns of age-3-ocean adults in 2008 completed the adult returns from the 2005 tagging.

For the 2008 tagging season, we continued to use a modified study design first used in 2007. In our original (2005-2006) study design, fish detected at McNary Dam were assigned as replicate "releases" to form treatment groups. This design provided a known number of fish in each treatment group. However, efforts to tag the number of fish needed for this design (301,000) have produced unpredictable results. In addition, concern was expressed about the impact on the run in general of tagging a large portion of the overall hatchery population.

Because of these concerns, we developed a new study design in 2007, in which numbers of fish arriving at McNary Dam tailrace are estimated. Estimated numbers assigned to each study group were based on a smaller number of tagged and released fish that were actually detected. Using this new design in 2007, we reduced the number of fish needed for tagging from 301,000 to a minimum of 111,222. In 2008, due to recent low smolt-to-adult return rates (SARs), we increased the tagging goal to 120,000 fish.

Although Snake River dam operations during spring 2008 were similar to those during 2007 (a delayed start of collection and transportation), we were able to begin tagging as planned due to prior agreement with agency and tribal managers. We began tagging on 22 April and expected to finish on 15 May. On 24 April, fish collection was inadvertently halted, and as a result we lost one replicate. However, due to the late arrival of hatchery spring/summer Chinook salmon at Lower Granite Dam, we were able to continue tagging until 17 May. The extended tagging schedule allowed us to replace the lost replicate.

From 22 April to 17 May 2008, we released a total of 122,028 hatchery spring/summer Chinook salmon. Of these fish, 28,820 were transported by truck and released below Ice Harbor Dam, 42,435 were transported by truck and returned to Lower Granite Dam for release into the tailrace, and 50,773 fish were released directly into the Lower Granite Dam tailrace with no transportation. All three study groups were released simultaneously.

Overall estimated survival to McNary Dam was 83.1% for fish released at Ice Harbor Dam, 73.5% for fish released at Lower Granite Dam, and 74.3% for reference fish. Based on these survival estimates, we estimated numbers of fish from each group arriving at McNary Dam tailrace at 23,952 from the Ice Harbor group, 31,059 from the McNary group, and 37,398 from the reference group. Detection rates at McNary Dam based on release numbers were 24.8, 14.9, and 17.4% for the respective Ice Harbor Dam, Lower Granite Dam, and reference groups.

From releases of tagged juveniles in 2008, adult returns will begin in 2009 (jacks) and will be complete in 2011. At Bonneville Dam, the principle adult recovery site for this study, we detected 15 age-3-ocean adults from 2005, 729 age-2-ocean adults from 2006, and 59 jacks from 2007. Subsequent detections of these fish at Lower Granite Dam were 6 age-3-ocean, 662 age-2-ocean, and 55 jacks from the same respective tagging years.

Returns of age-3-ocean adults in 2008 marked the completion of returns from fish marked as juveniles in 2005. However, in 2005, we released only 47,352 of the 301,000 hatchery spring/summer Chinook salmon planned for the study. This loss was partly due to a delay in availability of the newly constructed tagging facility and partly due to a turbidity event, which flushed remaining target fish past the dam. In addition to the inadequate numbers of fish released, SARs for fish that entered the ocean in spring 2005 were low.

Fish had been tagged in 2005 according to the original study design (using actual detections to form "replicate" treatment groups). Based on this design, with complete adult returns of fish released in 2005 (jacks through age-3-ocean), SARs were 0.31 (95% CI 0.13-0.49) for the Ice Harbor group, 0.03 (95% CI 0.00-0.08) for the Lower Granite group, and 0.06 (95% CI 0.00-0.13) for the reference group.

Because of the inadequate numbers of fish released and very low adult returns from 2005 (1 Lower Granite fish and 4 reference fish), we also estimated SARs for these juveniles using the modified study design. Based on the estimated numbers of juveniles surviving to McNary Dam tailrace, total adult returns for all three groups increased from 17 to 48. Using the estimated numbers, SARs were 0.22 (95% CI 0.13-0.32) for the Ice Harbor group, 0.10 (95% CI 0.04-0.17) for the Lower Granite group, and 0.10 (95% CI 0.05-0.15) for the reference group. This produced a SARs ratio of 0.47 (95% CI 0.22-1.01) for Lower Granite to Ice Harbor Dam groups. However, even after analyses using the modified data, the resulting wide confidence intervals indicated that more data is needed before any definite conclusions can be reached.

CONTENTS

INTRODUCTION

Populations of Snake River spring/summer Chinook salmon *Oncorhynchus tshawytscha* have declined extensively since completion of the Federal Columbia River Hydropower 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 roughly proportional to direct mortality suffered by smolts during downstream migration through the completed system.

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, adult return rates of Snake River Chinook salmon have not increased to mean levels that existed prior to dam construction (Schaller et al. 2007). During the early 2000s, adult returns exceeded 2%, the minimum level some consider necessary for recovery (Scheuerell and Williams 2005); however, these increased SARs were not sustained throughout the decade.

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. That is, mortality not expressed until after these fish have passed through the Federal Columbia River Power System (Budy et al. 2002). The concept of hydropower-related latent mortality was developed during the multi-agency process known as the Plan for Analyzing and Testing Hypotheses (Marmorek et al. 1998). Latent mortality was hypothesized as a possible explanation for the relatively greater loss in productivity postulated for upper river populations (i.e., Snake River) vs. lower river populations (downstream from McNary Dam) of spring/summer Chinook salmon (Schaller et al. 1996, 2007).

Based on their estimated spawner and recruit data, Schaller et al. (1999, 2007) and Deriso et al. (2001) concluded that productivity declined more for upriver stocks, and that these declines were most affected by hydropower development. This reduction was thought to have occurred primarily after completion of the three final dams on the Snake River. Furthermore, this differential decline was greater than could be explained by differences in direct mortality caused by the additional dams. Schaller et al. (1999, 2007) argued there was little evidence that factors unrelated to the hydropower system could account for the differences in productivity and survival between upstream and downstream stocks.

This conclusion has been questioned, and evidence provided by other researchers (Zabel and Williams 2000; Hinrichsen 2001) that several other factors could be at least partially responsible for differences in productivity between salmon populations from the two areas. 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 through Snake River dams and reservoirs causes latent mortality in Snake River yearling Chinook salmon smolts. Specifically, the study will evaluate smolt-to-adult return rates (SARs) of yearling Chinook salmon passing McNary Dam. Comparisons of SARs will be made between three study groups: fish transported and released to the tailrace of Ice Harbor Dam, fish transported and released to the tailrace of Lower Granite Dam (which will require the latter to pass three additional dams and reservoirs to reach McNary Dam), and reference fish released to the tailrace of Lower Granite Dam without transport.

Here we present final results from study fish released in 2005, results to date from study fish released in 2006 and 2007, and information on tagging of juveniles in 2008.

JUVENILE RELEASES DURING 2008

Methods

Juvenile Collection and Tagging

Our original study design was to use fish detected at McNary Dam to form two treatment groups and one reference group for comparison (Marsh et al. 2007). However, because detection probability at McNary Dam was only 0.25, we would need to tag and release at least 301,000 fish upstream from the dam. This number would be needed in order to detect the requisite 58,100 juveniles for meaningful comparison of adult returns among the three study groups.

In 2006, our juvenile tagging effort was slowed by the arrival of large numbers of steelhead, which increased the time required to sort study fish from other species. The 2006 tagging effort was also restricted by limits on the number of driving hours permitted for transport truck drivers (Marsh et al. 2007). These obstacles remain as potential impediments to future tagging efforts of this scope. In addition, concerns were raised about possible effects to the general population from tagging a large proportion of hatchery spring/summer Chinook salmon. In response to these concerns, we changed our study design in 2007 to use an estimated number of juveniles reaching the tailrace of McNary Dam instead of the actual detected number.

In 2008, we planned to collect and PIT-tag Snake River hatchery spring/summer Chinook salmon at Lower Granite Dam from 22 April to 15 May 2007. This schedule was based on our own observations from previous studies, which have shown that these fish generally begin passing Lower Granite Dam around 20-25 April and end by mid-May.

Collection and handling techniques, including use of a recirculating anesthetic water system, followed the methods of Marsh et al. (1996, 2001). Tagging for each of 10 replicates was to be conducted in 2-d blocks over 20 total days. On the first day of each 2-d block, reference fish (LN) 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 Ice Harbor Dam transport (IH), and one for Lower Granite Dam transport (LG). All tagging had to be 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. Upon arrival at Ice Harbor Dam (approximately 1900), IH treatment fish were released into the juvenile fish facility bypass pipe. A circuitous route was devised for the Lower Granite Dam (LG) release group so that the truck carrying these fish returned to Lower Granite Dam at the same time the other truck was arriving at Ice Harbor Dam. Upon return to Lower Granite Dam, trucked fish were released through a pipe that runs along the top of the juvenile fish facility bypass pipe. Immediately following release of the Lower Granite treatment group, the reference group was released through the same pipe.

Evaluation will be based on annual ratios of SARs, that is, SAR_{LG}/SAR_{IH}, or (LG/IH ratio). Note that as a ratio of SARs from groups "released" at McNary Dam, LG/IH is a measure of differential survival below McNary Dam. As such, it is analogous to the differential mortality parameter, *D*, which has been computed for the comparison of transported to inriver fish below Bonneville Dam. Thus, an LG/IH ratio significantly less than 1.0 would indicate significant latent mortality for fish that passed through the hydropower system between Lower Granite and Ice Harbor Dams.

Sample sizes for each year of this study were designed to provide an 80% probability ($\beta = 0.20$) of detecting a significant difference from 1.0 using a one-sided hypothesis test at $\alpha = 0.05$. Thus, differences will be detectable if the true LG/IH is less than or equal to 0.80 (i.e., survival is at least 20% lower for fish released at Lower Granite Dam) and SAR_{IH} is at least 1.5% (see below).

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

$$\ln\left(\frac{\mathrm{LG}}{\mathrm{IH}}\right) - (t_\alpha + t_\beta) \times \mathrm{SE}\left[\ln\left(\frac{\mathrm{LG}}{\mathrm{IH}}\right)\right] \approx 0$$

and

$$\mathrm{SE}\left[\ln\left(\frac{\mathrm{LG}}{\mathrm{IH}}\right)\right] \approx \sqrt{\left(\frac{1}{\mathrm{n_{IH}}} + \frac{1}{\mathrm{n_{LG}}}\right)} = \sqrt{\frac{2}{\mathrm{n}}}$$

where n is the number of adult returns per treatment, and $n_{IH} = n_{LG}$ (n for Ice Harbor Dam and Lower Granite Dam tailrace groups set equal for simplicity). The previous two statements imply that the required number of adults is:

$$n \approx \frac{2\left(t_{\alpha} + t_{\beta}\right)^2}{\left(\ln\left(\frac{LG}{IH}\right)\right)^2}$$

Again, as we set α = 0.05 and β = 0.20, and if we expect SAR_{IH} to be at least 1.5%, then the number of detections needed at McNary Dam are listed as follows:

True LG/IH	n	N_{IH}	$N_{LG} = N_{IH}/(LG/IH)$	N_{Total}
0.80	333	22,200	27,750	49,950

where N denotes the number of juveniles needed per treatment.

These calculations provided the sample sizes needed for each "release group" at McNary Dam. However, these "release" groups are formed from detections of treatment groups at McNary Dam. Therefore, they include only the proportion of tagged fish released upstream from McNary Dam that were detected at the dam. However, not all tagged fish that pass McNary Dam are detected, and at least some mortality is likely to occur in treatment groups before they arrive at the dam. Therefore, the number of tagged fish needed for release upstream from McNary Dam was considerably larger than the number needed to determine differences among SARs.

To determine the total number of fish needed for tagging, we used an assumed probability of survival to McNary Dam for Ice Harbor and Lower Granite release groups. These assumed probabilities of survival were based on survival estimates from our 2006 study year, and accounted for fish removed for transportation. For 2008, we estimated that the proportion of fish surviving to McNary Dam tailrace was 0.830 for fish released to Ice Harbor Dam tailrace and 0.657 for fish released to Lower Granite Dam tailrace.

Thus, to obtain the necessary number of study-fish detections at McNary Dam required releases of approximately 26,747 fish (22,200/0.83) to Ice Harbor Dam tailrace and 42,237 fish (27,750/0.657) to Lower Granite Dam tailrace. An additional 42,237 non-transported fish were released directly into Lower Granite Dam tailrace to serve as reference fish in evaluation of potential transport effects. Therefore, the total tagging requirement was 111,222 fish. Because of the low SARs experienced over the past several years, we increased the release number to 120,000 fish.

Adult Recovery and Data Analyses

Bonneville Dam will serve as the principal adult recovery site for this study. Using this site for adult recovery will maximize study SARs by avoiding potential losses from upstream passage mortality and mainstem fisheries above the dam. Data acquired from other areas will be considered ancillary. To analyze results, statistical tests will be applied in 2011, when adult returns for the 2008 study releases are complete. For each year of releases, the study will provide LG/IH ratios based on estimates of juvenile survival to McNary Dam. Confidence intervals for LG/IH ratios will be calculated using the ratios of these estimates and their associated variances (Burnham et al. 1987).

We assumed the true distribution of LG/IH ratios was approximately log-normal, and therefore calculated the confidence intervals on the natural log scale and then transformed the endpoints back to the original scale. Note that estimates of variance used in these intervals had to be adjusted to account for variation in the estimation process, which estimated the number of juveniles surviving and being detected in the tailrace of McNary Dam. Methods used for these estimates and for calculating their variances are provided in Appendix B.

Results and Discussion

The latent mortality study began in 2005, and 2008 was the fourth study year of juvenile tagging and the first study year in which adult returns from a juvenile tagging year were complete. Juvenile tagging in 2008 was fully successful; in contrast, the completed adult returns from 2005 juvenile tagging were dismal, illustrating why multiple years of study are often required to obtain meaningful results in research studies of Chinook salmon.

For the first time in 2008, we achieved our pre-season tagging objectives. During the first 3 study years, we were not able to tag the number of juvenile fish specified in the study design. These outcomes were the result of various obstacles, including construction delays and early season turbidity in 2005, an influx of non-target fish in 2006, and delays to fish collection operations in 2007, which postponed the start of tagging from 23 April to 2 May. Our tagging effort in 2008 started slowly due to the cold, wet spring, which slowed run-timing for all species. In addition, on the evening of 24 April, fish collection was inadvertently halted, and this resulted in the loss of one replicate.

Hatchery spring/summer Chinook salmon usually begin reaching Lower Granite Dam in large numbers between 20 and 25 April, with the run usually lasting 3-4 weeks and ending around mid-May. For this reason, we planned to begin tagging around 22 April and end around 15 May. However, in 2008 hatchery Chinook salmon did not begin to arrive in large numbers until 29 April, the day we were collecting for what should have been the first day of our fourth 2-d replicate block. Thus the loss of fish on 24 April (the first day of our second 2-d replicate block) did not result in a lost treatment replicate. We had missed collecting fish during a time when fish numbers arriving at the dam were still quite low. We were able to extend the tagging period and ultimately tagged two to three times more fish, since numbers of fish arriving at the dam remained high until the end of the tagging period.

Due to the late run-timing, we were initially between 4,400 and 8,600 fish behind in each treatment group. However, once fish began arriving in large numbers, we attempted to surpass the daily tagging goals by as many fish as possible over the remainder of the tagging season. Because reference fish were the only group tagged on the first day of the 2-d replicate block (i.e., all personnel tagged the same group), the deficit in this group was easily eliminated. In fact, over the last three replicates, we had to slow tagging efforts down because we had turned the deficit into an excess of over 5,000 fish.

Because the Ice Harbor and Lower Granite truck treatment groups were both tagged on the same day (i.e., tagging personnel were split between two groups), making up the deficit in each of these groups was more difficult. However, by the end of the tagging period, we had eliminated the deficit and exceed the tagging goal in two of the three treatment groups: we exceeded the tagging goal by 50 in the Ice Harbor treatment group and 6,000 in the reference group. While we were unable to eliminate the deficit in the Lower Granite Dam group, we did reduce it from 8,600 to 3,000 fish. Overall, we exceeded our total tagging goal of 120,000 by nearly 3,000 fish.

From 23 April to 17 May, we tagged 122,953 hatchery yearling spring/summer Chinook salmon and released a total of 122,028 (Table 1). Fish were divided into three groups, with 28,820 released below Ice Harbor Dam (IH), 42,435 released into Lower Granite Dam tailrace after being transported by truck for an equal amount of time (LG), and 50,773 released as reference fish into Lower Granite Dam tailrace with no transportation (LN).

Post-tagging mortality was determined using the reference group (LN), which was held for 24-h prior to release. Average post-tagging mortality for the entire tagging period was 1.34%, with daily values ranging from 0.07 to 3.11%. This rate was higher than observed in past tagging efforts using hatchery spring/summer Chinook salmon at Lower Granite Dam. The bulk of the mortality occurred on 2 and 5 May. Excluding mortality on those dates, the overall average post-tagging mortality rate would have been 0.88%, similar to mortality rates observed in previous years.

Mortalities were examined for any obvious injury that would indicate problems with tagging technique (e.g., punctured kidney or other organ damage). We observed that 2.0% of mortalities had been described as descaled at the time of tagging, while only 0.2% of the entire tagging population was so described. Body injury also may have contributed to mortality, as 1.16% of mortalities had been recorded as having some form of body injury at tagging, while only 0.64% of all tagged fish had records of body injury at tagging. This effect of descaling and body injury on post-tagging mortality was similar to that found in previous studies of hatchery spring/summer Chinook salmon at Lower Granite Dam.

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 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	8,736	15,289
4 May	5 May	6 May	7,882	
5 May	6 May	6 May	9,865	17,747
6 May	7 May	8 May	6,306	
7 May	8 May	8 May	6,288	12,594
8 May	9 May	10 May	5,911	
9 May	10May	10 May	7,304	13,215
11 May	12 May	13 May	4,943	
12 May	13 May	13 May	10,302	15,246
13 May	14 May	15 May	4,885	
14 May	15 May	15 May	9,491	14,376
15 May	16 May	17 May	3,765	
16 May	17 May	17 May	10,058	13,823

* Replicate was postponed because not enough fish were collected

Estimated survival to McNary Dam was 83.1% for the Ice Harbor transport treatment (IH), 73.5% for the Lower Granite transport treatment (LG), and 74.3% for the Lower Granite Dam reference group (LN; Table 2). Based on these survival estimates, we estimated numbers of tagged fish reaching McNary Dam tailrace at 23,952 Ice Harbor treatment fish, 31,059 Lower Granite treatment fish, and 37,398 reference fish. When adult returns are complete, these juvenile numbers will be used to determine SARs for comparisons among the three groups.

Table 2. Number of PIT-tagged hatchery yearling spring/summer Chinook salmon released by treatment group for evaluation of latent mortality, 2008. 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
Lower Granite trucked	42,435	73.5	31,059
Reference	50,773	74.3	37,398
Ice Harbor trucked	28,820	83.1	23,952

While survival rates for the 2008 Ice Harbor Dam (IH) release group were lower than the previous three years, survival rates for 2008 Lower Granite Dam trucked (LG) and non-transport (LN) release groups were lower than those from 2005 and 2007, but higher than those from 2006. As in past years, the similarity in survival rates between the LG and LN groups would indicate that transporting fish in a truck had little or no effect on juvenile survival through the hydropower system. We await adult returns to determine if there are any impacts of trucking on SARs. Adults from 2008 releases will begin returning in 2009 (jacks), with complete adult returns expected in 2011.

ADULT RECOVERIES FROM MIGRATION YEAR 2005

Methods

Juvenile Collection and Tagging

Juvenile collection and tagging methods used in 2005 were the same as those described above for tagging and release in 2008. However, as previously discussed, our original study used actual detections of tagged fish at McNary Dam rather than an estimated number passing the dam to calculate SARs (Marsh et al. 2006). Thus, our original study design in 2005 required the release of approximately 71,475 fish (16,600/0.929/0.250) into Ice Harbor Dam tailrace and 114,799 fish (20,750/0.723/0.250) into Lower Granite Dam tailrace. An additional 114,799 non-transported fish were released directly into Lower Granite Dam tailrace to control for potential transport effects. This brought the total tagging requirement to 301,073 fish. This target was not reached in 2005 due to a significant delay in completion of our tagging facility as well as a turbidity event shortly after the start of tagging.

Adult Recovery and Data Analyses

Bonneville Dam is the principal adult detection site for this study. Using this site for adult detection maximized study SARs by avoiding losses of adults from upstream passage mortality and from mainstem fisheries above Bonneville Dam. Adult detection data were acquired from other areas, but were considered ancillary. Confidence intervals for LG/IH ratios were calculated using the method of Burnham et al. (1987) to estimate ratios and their associated empirical variances. An explanation of these procedures can be found in Appendix B.

Results

Juvenile Collection and Tagging

Details of juvenile collection and tagging in 2005 were reported by Marsh et al. (2006), and numbers of fish released for all treatments in 2005 are shown in Table 3. Total tagging and release numbers by treatment are shown in Appendix Table A1.

Our original study design was based on comparisons of fish detected at McNary Dam, so juvenile fish were monitored as they migrated downstream after release (Table 4 and Appendix Table A2). The purpose of the non-transported group released at Lower Granite Dam (LN group) was to provide a reference for potential effects of transport (trucking). Based on juvenile detections of the 2005 releases, there did not seem to be any effect of trucking at the juvenile stage, as the trucked (LG) and reference (LN) groups released at Lower Granite were detected 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 2005. Numbers of fish released are also shown.

Collection date	Tag date	Release date	Number of fish released	Release number per 2-d block
2 May	3 May	4 May	5,696	
3 May	4 May	4 May	6,822	12,518
4 May	5 May	6 May	5,018	
5 May	6 May	6 May	6,108	11,126
8 May	9 May	10 May	5,040	
9 May	10 May	10 May	2,679	7,719
10 May	11 May	12 May	1,398	
11 May	12 May	12 May	1,932	3,330
12 May	13 May	14 May	1,565	
13 May	14 May	14 May	3,384	4,949
15 May	16 May	17 May	2,693	
16 May	17 May	17 May	1,703	4,396
17 May	18 May	19 May	1,480	
18 May	19 May	19 May	1,669	3,149

Table 4. Numbers of PIT-tagged hatchery yearling spring/summer Chinook salmon released by treatment for evaluation of extra mortality in 2005. The number and percent detected at McNary Dam by treatment group is also shown.

Release group	Number released	Number detected at McNary Dam	Percent detected at McNary Dam
Lower Granite trucked (LG)	13,435	3,686	27.44
Reference (LN)	22,890	6,278	27.43
Ice Harbor trucked (IH)	10,862	3,874	35.67

Adult Recovery and Data Analysis

We began recovering jacks in 2006 from study fish released at Lower Granite Dam in 2005. In August 2008, we completed recoveries from the 2005 release year with the collection of age-3-ocean adults. Adult returns from the 2005 study year were very low, with a total of only 17 adults returning from all study fish detected at McNary Dam during the juvenile migration. Because of the small number of fish tagged and the poor returns, we conducted supplementary analyses using the modified study design that began in 2007. The modified design uses an estimate of the number of juveniles that reached the McNary Dam tailrace rather than actual detections at the dam (Table 5 and Appendix Table A3). Use of these estimates increased the number of adults from 17 to 48, allowing for more useful comparisons among treatments.

Table 5. The number of PIT-tagged hatchery yearling spring/summer Chinook salmon released at Lower Granite Dam after trucking (LG), released at Lower Granite Dam without trucking (LN), and released at Ice Harbor Dam (IH) for evaluation of latent mortality in 2005. Survival from release to McNary Dam, the number of fish transported from a collector dam, and the estimated number of fish arriving in the tailrace of McNary Dam are also shown.

Treatment group	Number released	Estimated survival to McNary Dam (%)	Transported	Estimated survival to McNary Dam (n)
Lower Granite (LG)	13,435	0.744	308	9,690
Reference (LN)	22,890	0.749	486	16,647
Ice Harbor (IH)	10,862	0.876	43	9,470

Smolt-to-Adult Return Ratios—Using only the 17 fish detected at McNary Dam as juveniles, overall estimated SARs were 0.31 for Ice Harbor fish, 0.03 for Lower Granite fish, and 0.06 for reference. These SARs were based on the 12, 1, and 4 adults returning from each respective treatment (Table 6). Based on these SARs, the LG/IH ratio was 0.09 (95% CI, 0.01-0.71), indicating substantial latent mortality due to migration past the three lower Snake River dams. When we compared Lower Granite and reference groups, the LG/LN ratio was 0.43 (95% CI, 0.05-4.02); however, the confidence interval for this ratio was again wide, indicating too much variation to determine whether a trucking effect existed.

Table 6. The number of juveniles, adults, and the SARs for PIT-tagged hatchery yearling spring/summer Chinook salmon detected at McNary Dam from fish released at Lower Granite Dam after trucking (LG), released at Lower Granite Dam without trucking (LN), and released at Ice Harbor Dam (IH) for evaluation of latent mortality in 2005.

Juvenile numbers	Returns by age-class			SAR (95% CI)	SAR ratio: LG/IH or LG/LN (95% CI)
	Jack	2-ocean	3-ocean		
Ice Harbor trucked (IH)					
3,874	0	9	3	0.31 (0.13-0.49)	
Lower Granite trucked (LG)					
3,686	0	1	0	0.03 (0.00-0.08)	0.09 (0.01-0.71)
Reference (LN)					
6,278	0	2	2	0.06 (0.00-0.13)	0.43(0.05-4.02)

Using the 48 fish estimated to have arrived in McNary Dam tailrace as juveniles, SARs were 0.23 for Ice Harbor fish, 0.13 for Lower Granite fish, and 0.11 for reference fish (Table 7). Based on these SARs, the LG/IH ratio was 0.47 (95% CI, 0.22-1.01), indicating there may have been latent mortality caused by migration through the three lower Snake River dams, although the confidence interval was wide. When we compare the Lower Granite and reference treatments, the LG/LN ratio was 1.01 (95% CI, 0.45-2.25). Again, there was too much variation to determine whether there was an effect from trucking (either positive or negative) based on this comparison.

Table 7. Number of juveniles, adults, and the SARs for PIT-tagged hatchery yearling spring/summer Chinook salmon estimated to have arrived in McNary Dam tailrace from fish released at Lower Granite Dam after trucking (LG), released at Lower Granite Dam without trucking (LN), and released at Ice Harbor Dam (IH) for evaluation of latent mortality in 2005.

Juvenile numbers	Returns by age-class			SAR (95% CI)	SAR ratio: LG/IH or LG/LN (95% CI)
	Jack	2-ocean	3-ocean		
Ice Harbor trucked (IH)					
9,470	0	13	8	0.22 (0.13-0.32)	
Lower Granite trucked (LG)					
9,690	0	9	1	0.10 (0.04-0.17)	0.47 (0.22-1.01)
Reference (LN)					
16,647	1	12	4	0.10 (0.05-0.15)	1.01 (0.45-2.25)

Conversion Rates--Overall adult conversion rates from Bonneville to Lower Granite Dam ranged from 33.3 to 100.0% for fish detected at McNary Dam as juveniles (not adjusted for Zone 6 fishery; Table 8).

Using adults estimated to have arrived as juveniles at McNary Dam, the overall adult conversion rates (not adjusted for Zone 6 fishery) from Bonneville to Lower Granite Dam ranged from 20.0 to 92.3% (Table 8). The only jack Chinook salmon that crossed Bonneville did not cross McNary Dam. Using estimated juveniles at McNary Dam, the age-3-ocean adults from all three treatment groups converted at a lower rate than their age-2-ocean counterparts, and the reference group (LN) performed the poorest of the three groups. As observed in previous studies, most loss of adults occurred between Bonneville and McNary Dam (Table 9).

Table 8. Percentage of adult PIT-tagged hatchery spring/summer Chinook salmon detected as adults at Bonneville Dam and subsequently Lower Granite Dam (the conversion rate). Detections are shown for study fish actually detected as juveniles at McNary Dam and for those estimated to have arrived at McNary Dam in 2005.

	Detected at Bonneville Dam	Detected at Lower Granite Dam	Conversion rate
		Detected juveniles at McNary Dam	
Jacks			
Ice Harbor (IH)	0	0	--
Lower Granite (LG)	0	0	--
Reference (LN)	0	0	--
Age-2-ocean adults			
Ice Harbor (IH)	9	8	88.89
Lower Granite (LG)	1	1	100.00
Reference (LN)	2	2	100.00
Age-3-ocean adults			
Ice Harbor (IH)	3	1	33.33
Lower Granite (LG)	0	0	--
Reference (LN)	2	0	0.00
Totals			
Ice Harbor (IH)	13	9	75.00
Lower Granite (LG)	1	1	100.00
Reference (LN)	4	2	50.00
		Estimated juveniles at McNary Dam	
Jacks			
Ice Harbor (IH)	0	0	--
Lower Granite (LG)	0	0	--
Reference (LN)	1	0	0.00
Age-2-ocean adults			
Ice Harbor (IH)	13	12	92.31
Lower Granite (LG)	10	9	90.00
Reference (LN)	12	10	83.33
Age-3-ocean adults			
Ice Harbor (IH)	8	4	50.00
Lower Granite (LG)	2	1	50.00
Reference (LN)	5	1	20.00
Totals			
Ice Harbor (IH)	21	16	76.19
Lower Granite (LG)	12	10	83.33
Reference (LN)	18	11	61.11

Table 9. Adult survival (percent) from Bonneville Dam to McNary Dam and from McNary Dam to Lower Granite Dam for hatchery spring/summer Chinook salmon estimated to have arrived as juveniles in the McNary Dam tailrace after having been PIT-tagged and released from Lower Granite Dam in 2005.

Reach	Treatment group	Detected at first dam (n)	Subsequently detected at second dam (n)	Conversion rate
Jacks				
BON to MCN	Ice Harbor (IH)	0	0	--
	Lower Granite (LG)	0	0	--
	Reference (LN)	1	0	0.00
MCN to LGR	Ice Harbor (IH)	0	0	--
	Lower Granite (LG)	0	0	--
	Reference (LN)	0	0	--
Age-2-ocean adults				
BON to MCN	Ice Harbor (IH)	13	12	92.31
	Lower Granite (LG)	10	9	90.00
	Reference (LN)	12	10	83.33
MCN to LGR	Ice Harbor (IH)	12	12	100.00
	Lower Granite (LG)	9	9	100.00
	Reference (LN)	11	11	100.00
Age-3-ocean adults				
BON to MCN	Ice Harbor (IH)	8	5	62.50
	Lower Granite (LG)	2	2	100.00
	Reference (LN)	5	1	20.00
MCN to LGR	Ice Harbor (IH)	5	4	80.00
	Lower Granite (LG)	2	1	50.00
	Reference (LN)	1	1	100.00
Totals				
BON to MCN	Ice Harbor (IH)	21	17	80.95
	Lower Granite (LG)	12	11	91.67
	Reference (LN)	18	11	61.11
MCN to LGR	Ice Harbor (IH)	17	16	94.12
	Lower Granite (LG)	11	10	90.91
	Reference (LN)	12	12	100.00

Travel Time—Median travel time of adults from Bonneville to Lower Granite Dam for fish detected as juveniles at McNary Dam ranged from 12.0 to 15.0 d, with age-2-ocean adults making the trip in less time (Table 10). For study fish estimated to have arrived in McNary Dam tailrace as juveniles, median travel times from Bonneville Dam to Lower Granite Dam ranged from 13.0 to 21.0 d, with age-2-ocean adults making the trip in less time (Table 10). For both age-2-ocean and age-3-ocean adults, fish from the Lower Granite treatment (LG) showed the slowest travel times, while the other two treatment groups had similar travel times for both age classes.

Table 10. Median travel times from Bonneville Dam to Lower Granite Dam for adult hatchery spring/summer Chinook salmon detected at McNary Dam as juveniles after having been PIT-tagged as juveniles in 2005.

Age class	Treatment group	Number of adults	Travel time from Bonneville Dam to Lower Granite Dam (d)
	Detected juveniles at McNary Dam		
Jacks	Ice Harbor (IH)	0	--
	Lower Granite (LG)	0	--
	Reference (LN)	0	--
Age-2-ocean	Ice Harbor (IH)	8	12.5
	Lower Granite (LG)	1	12.0
	Reference (LN)	2	12.5
Age-3-ocean	Ice Harbor (IH)	1	15.0
	Lower Granite (LG)	0	--
	Reference (LN)	0	--
	Estimated juveniles at McNary Dam		
Jacks	Ice Harbor (IH)	0	--
	Lower Granite (LG)	0	--
	Reference (LN)	0	--
Age-2-ocean	Ice Harbor (IH)	12	13.0
	Lower Granite (LG)	9	16.0
	Reference (LN)	10	13.5
Age-3-ocean	Ice Harbor (IH)	4	17.0
	Lower Granite (LG)	1	21.0
	Reference (LN)	1	16.0

Length at Tagging—Using only fish detected at McNary Dam as juveniles, returning adults from the reference group were larger at tagging than returning adults from either the Ice Harbor or Lower Granite treatment groups. Age-3-ocean adults were larger at tagging than age-2-ocean adults (Table 11). This observation contrasted with our previous observations of wild fish over the years, where the largest juveniles typically returned as jacks and the smallest returned as age-3-ocean adults.

Another contrasting observation was that in fish from the Lower Granite and Ice Harbor treatment groups, average fork length at tagging was smaller for fish that returned as adults than for fish that did not return. In previous observations of wild fish, returning adults have typically been larger at tagging, on average, than fish that did not return. In the present study, only fish from the reference group showed larger-than-average juvenile fork lengths for returning adults than for their counterparts that did not return.

When we looked at the returning adults from study fish estimated to have arrived in McNary Dam tailrace as juveniles, we found nearly the same trends: adults from the reference group had been largest at tagging, and age-3-ocean adults had been larger at tagging than age-2-ocean adults (Table 11). The lone exception to this pattern was seen in adults from the reference group, which showed the typical pattern observed in wild spring/summer Chinook salmon, with jacks having been largest at tagging and age-3-ocean adults having been smallest.

In contrast to the results using only adults that had been detected as juveniles at McNary Dam, average fork length at tagging for fish estimated to have arrived as juveniles at McNary Dam was larger for fish that returned as adults than for their counterparts that did not return. This trend was found in all groups except the age-2-ocean Ice Harbor adults, which were smaller as juveniles than their counterparts.

Table 11. Average length at tagging of adult hatchery spring/summer Chinook salmon PIT-tagged as juveniles at Lower Granite Dam and detected at McNary Dam in 2005.

Age class	Treatment group	Average length at tagging for all fish (mm)	Number of returning adults	Average length at tagging for returning adults (mm)
	Detected juveniles at McNary Dam			
Jacks	Ice Harbor (IH)	136.7	0	--
	Lower Granite (LG)	135.9	0	--
	Reference (LN)	135.3	0	--
Age-2-ocean	Ice Harbor (IH)	136.7	9	132.3
	Lower Granite (LG)	135.9	1	131.0
	Reference (LN)	135.3	2	136.0
Age-3-ocean	Ice Harbor (IH)	136.7	3	135.0
	Lower Granite (LG)	135.9	0	--
	Reference (LN)	135.3	2	141.0
	Estimated juveniles at McNary Dam			
Jacks	Ice Harbor (IH)	136.7	0	--
	Lower Granite (LG)	135.9	0	--
	Reference (LN)	135.3	1	146.0
Age-2-ocean	Ice Harbor (IH)	136.7	13	133.2
	Lower Granite (LG)	135.9	10	136.0
	Reference (LN)	135.3	12	142.6
Age-3-ocean	Ice Harbor (IH)	136.7	8	137.6
	Lower Granite (LG)	135.9	2	138.0
	Reference (LN)	135.3	5	141.4

DISCUSSION

Marking of juvenile fish in 2005 did not begin until 4 May, two weeks past the scheduled date, due to delays in construction of the new tagging facility at Lower Granite Dam. Our tagging effort was further hindered by a turbidity event on 7-8 May, which rushed fish past the dam early in the season, drastically reducing the numbers of fish available for tagging. The cumulative effect of these events was that we tagged only seven replicates totaling 47,351 fish, just 16% of our original goal of 301,073. In 2005, juvenile survival from release to McNary Dam tailrace was the second highest in all four study years. River flow in 2005 was lower than the 10-year average (1996-2005), with a moderate amount of spill occurring from late April through mid-June. Ocean conditions were generally poor for juvenile salmonids entering the ocean in spring 2005.

Our initial tagging goals were established assuming a SAR of 1.5% for the Ice Harbor group and a LG/IH ratio of 0.80. Adult returns from the 2005 juvenile releases were very low, yielding an Ice Harbor group SAR of only one-fifth of the target SAR. This resulted in poor statistical power, and a confidence interval for the LG/IH ratio that was too wide to draw any conclusions about latent mortality. As with the overall LG/IH ratio, any attempt to discern a possible seasonal pattern to latent mortality was thwarted by the low adult returns.

Poor SARs also resulted in a confidence interval for the LG/LN comparison that was too wide to determine whether a trucking effect existed.

The 2005 study year was disrupted by various natural and man-made factors, each of which can affect the successful completion of field research. However, results from this study year will not be considered in isolation, but as part of a long-term effort to address the question of whether or not latent mortality occurs in migrating salmonids as a result of passage through lower Snake River federal hydropower projects. Though the data gained from 2005 releases were sparse, they may contribute to progress on this question when taken in context with results from future study years.

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APPENDIX A:

Tagging and Release Data for Hatchery Spring/Summer Chinook Salmon in 2005

Appendix Table A1. Totals by treatment of hatchery spring/summer Chinook salmon tagged at Lower Granite Dam in spring 2005. Reference fish were tagged and held 24-h before release to Lower Granite Dam tailrace. Lower Granite trucked fish were tagged, transported half-way to Ice Harbor Dam and back, and released to Lower Granite Dam tailrace. Ice Harbor fish were tagged, transported, and released to Ice Harbor Dam tailrace.

	Reference		Lower Granite trucked		Ice Harbor trucked	
Release Date	Tagged	Released	Tagged	Released	Tagged	Released
5/4/05	5,802	5,696	2,976	2,910	3,944	3,912
5/6/05	5,081	5,018	3,800	3,774	2,376	2,334
5/10/05	5,090	5,040	1,752	1,716	968	963
5/12/05	1,421	1,398	1,283	1,263	671	669
5/14/05	1,584	1,565	1,802	1,791	1,599	1,593
5/17/05	2,702	2,693	1,058	1,053	651	650
5/19/05	1,492	1,480	940	928	743	741

Appendix Table A2. Total hatchery spring/summer Chinook salmon released at Lower Granite Dam and detected at McNary Dam in spring 2005. Reference fish were tagged and held 24-h before release to the Lower Granite Dam tailrace. Lower Granite trucked fish were tagged, transported half-way to Ice Harbor Dam and back, and released to Lower Granite Dam tailrace. Ice Harbor fish were tagged, transported, and released into Ice Harbor Dam tailrace.

	Reference		Lower Granite Trucked		Ice Harbor trucked	
Release Date	Released	Detected	Released	Detected	Released	Detected
5/4/05	5,696	1,282	2,910	628	3,912	1,319
5/6/05	5,018	1,444	3,774	1,152	2,334	732
5/10/05	5,040	1,505	1,716	501	963	284
5/12/05	1,398	414	1,263	374	669	320
5/14/05	1,565	460	1,791	455	1,593	662
5/17/05	2,693	769	1,053	302	650	355
5/19/05	1,480	404	928	274	741	202

Appendix Table A3. Estimated numbers of hatchery spring/summer Chinook salmon arriving in McNary Dam tailrace in spring 2005 after release at Lower Granite and Ice Habor Dam. Reference fish were tagged and held 24-h before release to Lower Granite Dam tailrace. Lower Granite trucked fish were tagged, transported half-way to Ice Harbor Dam and back, and released to Lower Granite Dam tailrace. Ice Harbor fish were tagged, 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
5/4/05	5,696	4,292	2,910	1,966	3,912	3,087
5/6/05	5,018	3,531	3,774	2,758	2,334	2,150
5/10/05	5,040	3,684	1,716	1,105	963	853
5/12/05	1,398	966	1,263	1,060	669	629
5/14/05	1,565	1,216	1,791	1,394	1,593	1,482
5/17/05	2,693	1,901	1,053	795	650	594
5/19/05	1,480	1,045	928	707	741	706

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

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

by (1) and, $$\hat{SAR}_1^{\,2} = \left(\frac{n_1}{N_1}\right)^2 = \left(\frac{1}{R^2}\right)\left(\frac{n_1}{\hat{S}_1}\right)^2 \qquad (6)$$

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

$$\frac{\hat{V}(\hat{SAR}_1)}{\hat{SAR}_1^{\,2}} = \frac{\hat{V}(n_1)}{n_1^{\,2}} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}} = \frac{N_1\hat{SAR}_1(1-\hat{SAR}_1)}{n_1^{\,2}} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}}$$

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

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

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

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:

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