**Transportation of Juvenile Salmonids on the Columbia River, 2005:
Final report for the 2003 Hatchery Steelhead Juvenile Migration**

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Report of research by

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Walla Walla, Washington 99362-1876
Delivery Order E86960099

October 2007

EXECUTIVE SUMMARY

Since 1999, the National Marine Fisheries Service has conducted annual studies to evaluate transportation of Snake River steelhead smolts. In 2003, we began annual studies to evaluate transportation of upper Columbia River hatchery steelhead smolts. Here we report complete adult recovery data from Columbia River hatchery steelhead smolts marked with passive integrated transponder (PIT) tags and released in 2003.

From June 2005 through May 2006, we recovered age-2-ocean steelhead adults, completing adult returns from the 2003 study year. As smolts, these fish were tagged and released from Wells (246,056), Winthrop (49,241), Chelan (33,147), Eastbank (61,981), and Ringold (95,161) Hatcheries. At McNary Dam, PIT-tagged smolts that entered the juvenile bypass system were collected, and on alternate days, either diverted to transportation holding raceways or returned to the river through the full-flow bypass system. Transported fish were released below Bonneville Dam, while bypassed fish completed their juvenile migration in the river, along with study fish that did not enter the juvenile collection system at McNary Dam (inriver migrants).

From 2005 to 2006 we detected 198 age-2-ocean transported fish, 221 age-2-ocean full-flow bypassed fish, and 2,461 age-2-ocean inriver migrants from the 2003 releases. Based on all 2003 returns combined, smolt-to-adult return rates (SARs) were 2.34 for transported fish, 1.94 for full-flow bypass fish, and 2.45 for inriver migrants. These SARs resulted in a transport-to-inriver migrant ratio (T/I) of 0.96 (95% CI 0.86-1.07), a bypass-to-inriver migrant ratio (B/I) of 0.79 (95% CI 0.71-0.88), and a transport-to-bypass ratio of 1.21 (95% CI 1.04-1.40). Annual differential delayed mortality, *D*, was estimated at 0.97.

Of adults detected at Bonneville Dam, 71% of transported fish, 70% of full-flow bypass fish, and 71% of inriver migrant fish successfully migrated to McNary Dam (not adjusted for any take in the Zone 6 fishery). For age-1-ocean adults, median travel time from Bonneville Dam to McNary Dam was 19.0 d for transported fish, 16.5 for bypassed fish, and 17 d inriver migrants. For age-2-ocean adults, median travel times were faster, at 13.0 d for transported fish, 11.0 for bypassed fish, and 12.0 d for inriver migrants.

CONTENTS

INTRODUCTION

In 2005, we continued studies to evaluate transportation and release of juvenile fish below Snake and Columbia River dams to mitigate for losses from hydropower projects operated by the U.S. Army Corps of Engineers (USACE). Our primary objective was to compare adult returns of Chinook salmon and steelhead smolts transported to a release site below Bonneville Dam to those of their cohorts that migrated through the hydropower system under optimal conditions for inriver survival. Detections of our study fish that migrated inriver also provide data for annual estimates of juvenile survival between various points of release and Bonneville Dam tailrace (Muir et al. 2001).

In 2002, we began marking Columbia River spring Chinook salmon with passive integrated transponder (PIT) tags. Fish were tagged at various hatcheries in the mid-Columbia River to evaluate spring transport from McNary Dam. In 2003, we began marking hatchery steelhead for the same evaluations. PIT-tagged smolts collected at McNary Dam were either transported to below Bonneville Dam or returned to the river through the full-flow bypass pipe. Their cohorts that were not collected (and not detected) at McNary served as the inriver migrant group for comparisons

The full-flow bypass was completed at McNary Dam in 2002 (Axel 2005; Figure 1). This bypass is a large-diameter pipe fitted with four PIT-tag monitors, and it provides an alternate route to the tailrace for fish collected at the dam. The full-flow bypass is located upstream from the separator, and does not require mechanical dewatering to route fish to smaller pipes or flumes. Instead fish are detected in the 91.4-cm bypass pipe and returned directly to the tailrace to continue migrating inriver.

After adult returns were complete, we compared smolt-to-adult return rates (SARs) of transported smolts to those of full-flow bypassed fish and inriver migrants. Here we report final results from the 2003 steelhead tagging year, with adult returns through 2005-2006. Updated information is also provided on hatchery steelhead tagged for transportation in 2005 (Appendix B) and partial adult returns for Columbia River steelhead tagged in 2004 (Appendix C).

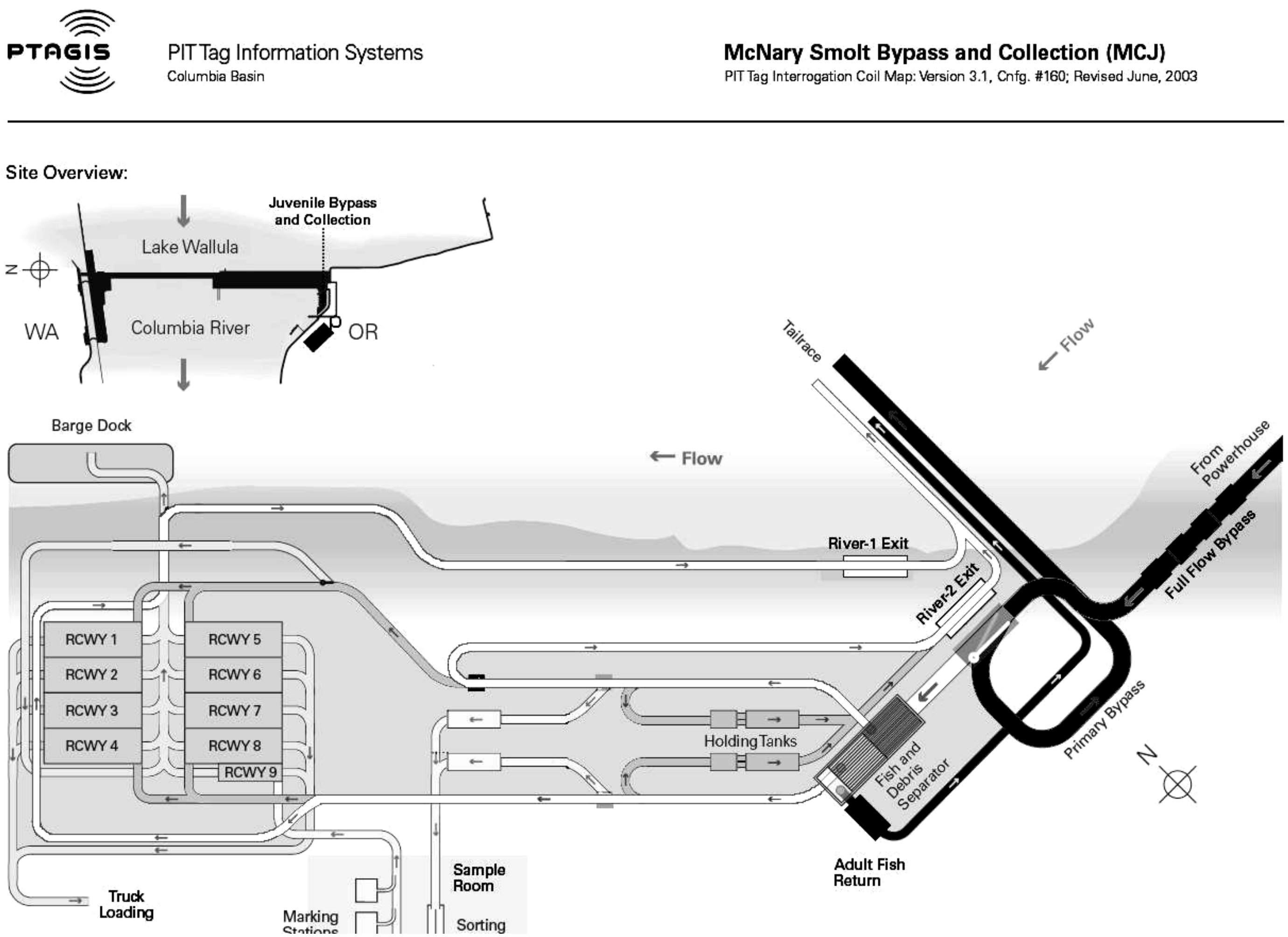


Figure 1. Configuration of juvenile fish facilities at McNary Dam showing the location of PIT-tag monitors on the full-flow bypass pipe, adult fish return, and transportation holding raceways. Diagram courtesy of Pacific States Marine Fisheries Commission.

METHODS

Sampling and Tagging of Juveniles in 2003

To evaluate transportation for fish originating in the Columbia River upstream from McNary Dam, we PIT-tagged and released steelhead that originated in hatcheries in this area. We attempted to tag numbers at each hatchery to approximate the same proportion that each respective hatchery population represented in the general population of steelhead. Transport, full-flow bypass, and inriver migrant groups were established when the fish arrived at McNary Dam.

On alternate days during the collection period, collected fish were either returned to the river through the full-flow bypass or passed over the separator and on to the separation-by-code PIT-tag diversion gates (Downing et al. 2001). To collect study fish for the transport group, we set the separation-by-code system to divert 100% of the tagged fish collected. Although full-flow bypassed fish were excluded from the inriver migrant study group, survival estimates were made from their downstream detections. These estimates were used in calculations of delayed mortality, *D*, of transported fish. In the absence of PIT-tag detections, we had to estimated the number of tagged fish in the inriver migrant group. Appendix D describes how this number was estimated using release numbers and estimated survival rates.

We calculated the number of fish needed to test 1) the null hypothesis, that there was no difference between the SARs of transported vs. inriver migrant fish, and 2) the alternative hypothesis, that the ratio of transported to inriver migrant SARs was at least 1.2. For a given type I error rate ($t_{\alpha/2}$, rejection of a true null hypothesis) and type II error rate (t_{β}, acceptance of a false null hypothesis), the number of fish was determined as follows:

$$\ln\left(\frac{T}{I}\right) - \left(t_{\frac{\alpha}{2}} + t_{\beta}\right) \times SE\left(\ln\left(\frac{T}{I}\right)\right) \approx 0 \qquad (1)$$

and

$$SE\left(\ln\left(\frac{T}{I}\right)\right) = \sqrt{\left(\frac{1}{n_T} + \frac{1}{n_I}\right)} = \sqrt{\frac{2}{n}} \qquad (2)$$

where n is the number of adult returns per treatment (for either n_T transport or n_I inriver migrant groups). The previous two statements imply that the number of adults needed is:

$$n = \frac{2\left(t_{\frac{\alpha}{2}} + t_{\beta}\right)^2}{\left(\ln\left(\frac{T}{I}\right)\right)^2} \qquad (3)$$

Therefore, if $\alpha = 0.05$ and $\beta = 0.20$, and if we wish to discern a difference of 20% ($T/B \geq 1.2$) between transported and full-flow bypassed fish, and if we expect a SAR for the transport group of at least 2.0%, then sample sizes required at McNary Dam were:

$n = 473$
$N_T = 23{,}650$
$N_B = 28{,}380$
Total juveniles = 52,030

Where N_T is the number of juveniles needed for the transport cohort and N_B is the number of fish needed for the full-flow bypass cohort (23,650 × 1.2).

The equations above provide the numbers of fish needed to form transport and bypass "release" groups from detections at McNary Dam. However, to assure detection of these numbers at the dam, larger numbers were needed for releases from upstream hatcheries. We estimated these numbers using detections at McNary Dam from a previous study, where PIT-tagged hatchery steelhead smolts were released into the Wells Dam tailrace between 24 April and 16 May, 2000. The fish passed McNary Dam primarily in May when the percentage of water spilled was fairly steady, at 40% of the total river flow. Survival of these fish to McNary Dam was 0.578 (SE 0.016) and the detection probability at the dam was 0.170 (SE 0.006). Using these values as a conservative estimate, we calculated that roughly 480,000 (52,030/0.578/0.170) PIT-tagged hatchery steelhead would need to be released from this area to satisfy the study design.

2003 Inriver Migration

Details on how migrating study fish were tracked as they pass through the collection systems at dams downstream from Lower Granite Dam are described by Marsh et al. (1996). Prior to 27 June 2003, McNary Dam was in bypass mode, with all tagged and untagged fish collected (except tagged fish from our Columbia River hatchery study) bypassed to the river after passing through PIT-tag detectors. Thus, the only fish transported were our tagged fish plus any by-catch of non-targeted fish.

Adult Recoveries and Data Analysis

In 2005-2006, we completed the recovery of adults tagged as juveniles in 2003. The procedures for data analysis described by Marsh et al. (1996) were modified as described in Appendix D to estimate the number of juvenile fish in the inriver migrant group.

Smolt-to-adult return percentages (SARs) were calculated for transport, full-flow bypass, and inriver (non-detected) cohorts as the number of adults returning in 2004-2006 and passing McNary Dam divided by the number of juveniles migrating past McNary Dam in 2003. Calculating the SARs for the transport and bypass groups was straightforward, since it was based on actual detections of juveniles and adults at McNary Dam. However, determining the juvenile number used in SAR calculations for the inriver (non-detected group) was more complicated. We estimated this number as:

$$\hat{N}_{nd} = N \times \hat{S}(1 - \hat{p})$$

where N was number released at mid-Columbia River hatcheries, S was estimated survival from release to McNary Dam, and p was estimated detection probability at McNary Dam.

Ratios of SARs were calculated for transport and bypass groups relative to the inriver (non-detected) group. To test the null hypotheses, that there was no difference in SARs between transported and inriver migrant (non-detected) fish or between bypassed and inriver migrant fish, we calculated 95% confidence intervals for these ratios. If the value 1.0 was outside the CI, the two passage routes were considered to have significantly different SARs.

Confidence intervals were constructed by natural-log transforming the estimates, calculating the interval on the transformed scale as ±1.96 SEs (1.96 = the z-value for $\alpha = 0.05$), and back-transforming the endpoints. This was done because ratios were assumed to be log-normally distributed. Derivation of the standard errors is shown in Appendix D.

RESULTS

Sampling and Tagging of Juveniles in 2003

Study fish were PIT tagged and released at Winthrop, Wells, Chelan, Eastbank, and Ringold Hatcheries (Table 1).

Table 1. Tag dates, releases dates, release numbers, and average tag lengths for yearling steelhead released from Columbia River hatcheries to evaluate transport from McNary Dam in 2003.

Hatchery	Tagging date	Hatchery release date	Number released	Average length at tagging (mm)
Winthrop	10-17 January 2003	30 April 2003	49,248	150.9
Wells	9 Sept–4 Oct. 2002	15 April–20 May 2003	246,088	94.0
Chelan	7-9 October 2002	4 April–2 May 2003	33,163	96.2
Eastbank	7-9 October 2002	15 April–20 May 2003	61,998	97.2
Ringold	10-15 October 2002	28-30 April 2003	95,159	119.9
Total released			485,656	

Inriver Juvenile Migration

Of 485,656 yearling steelhead released, 36,413 (7.5%) were detected at McNary Dam. Final dispositions for all 485,656 fish released are shown in Table 2.

Table 2. Final dispositions at McNary Dam for fish released from Columbia River hatcheries to evaluate transport from McNary Dam in 2003.

Hatchery	Diverted to transport	Diverted to full-flow bypass	Facility bypass	Separator adult bypass	Unknown	Not detected
Winthrop	1,139	1,468	94	35	4	46,508
Wells	7,985	9,796	861	482	15	226,949
Chelan	1,141	1,195	74	54	0	30,699
Eastbank	2,122	2,590	161	187	3	56,935
Ringold	2,970	3,748	267	8	14	88,152
Total	15,357	18,797	1,457	766	36	449,243

The vast majority of the steelhead marked were not released directly from hatcheries but were outplanted to various drainages (Methow, Okanogan, and Wenatchee) throughout the mid-Columbia River. Because a hatchery could outplant in one or more drainages, we believed it best to compute survival estimates based on release site (drainage or hatchery) rather than by the hatchery at which the fish were tagged. Based upon PIT-tag detections at John Day and Bonneville Dams, and on estuary detections in the pair-trawl system, we calculated estimates of survival for outplants in the Methow, Okanogan, and Wenatchee River drainages as well as for on-site releases from Wells and Ringold Hatcheries (Table 3).

Using the methods described in Appendix D, migration history data was analyzed resulting in an estimated 193,579 juvenile steelhead in the 2003 inriver migrant group (Table 4). The SAR calculation for the inriver migrant group is based on this number.

At McNary Dam, our initial goal was to divert 100% of the study fish collected and passed over the separator to transportation raceways. However, because of large numbers of fish passing the separation-by-code diversion gates, only 87.2% of the steelhead detected were transported from the dam during the smolt migration.

Table 3. Survival estimates from release site to the McNary Dam tailrace, from McNary Dam to Bonneville Dam tailrace, and from release site to Bonneville Dam tailrace for steelhead tagged for the 2003 McNary Dam transport evaluation.

		Estimated survival		
Release site	Number released	Release to McNary Dam	McNary to Bonneville Dam	release to Bonneville Dam
Drainage				
Methow	131,463	0.4061	0.7709	0.3131
Okanogan	73,528	0.4618	0.7709	0.3560
Wenatchee	95,161	0.4815	0.7709	0.3712
Hatchery				
Wells	90,345	0.3865	0.7709	0.2979
Ringold	95,159	0.6650	0.7709	0.5126
Total	485,656	0.4735	0.7709	0.3650

Table 4. The estimated number of migrating hatchery steelhead arriving at the McNary Dam tailrace in 2003 for the McNary Dam transport evaluation.

Release site	Number released	Estimated survival to McNary Dam	Estimated numbers arriving at McNary Dam*	Numbers of fish in each study group: Transported from McNary	Full-flow bypassed	Inriver migrants*
Drainage						
Methow	131,463	0.4061	53,387	3,956	4,896	44,039
Okanogan	73,528	0.4618	33,955	2,593	3,373	27,429
Wenatchee	95,161	0.4815	45,820	3,263	3,785	38,301
Hatchery						
Wells	90,345	0.3865	34,918	2,575	2,995	28,940
Ringold	95,159	0.6650	63,281	2,970	3,748	56,276
Totals	485,656	0.4735	229,958	15,357	18,797	193,579

***** Number is an estimate of the proportion released that arrived at McNary Dam, not the sum of releases from each site. These estimates vary due to differences in survival rates and arrival timing at McNary Dam for the various release sites.

Adult Recoveries and Data Analysis

At McNary Dam, we began recovering age-1-ocean adults in 2004 and finished with age-2-ocean adults in May 2006. Returns by study group and age-class are shown Table 5.

Table 5. Returns by study group and age-class of hatchery steelhead from McNary Dam transport study releases in 2003.

	Juvenile numbers	Returns by age-class: 1-ocean	2-ocean	SAR	T/I	95% CI	T/B
Transport	15,357	167	193	2.34	0.96	(0.78, 1.13)	1.21
Bypass	18,797	147	218	1.94	0.79	(0.82, 1.33)	
Inriver	193,579	2,322	2,422	2.45			

Relationship between Juvenile Migration Timing and SARs

For this study, inriver migrant fish were defined as those not detected at McNary Dam. Therefore, since we tagged and released study fish above McNary Dam, we were unable to determine SARs by juvenile migrant time for the inriver migrant adults, because we had no detection data on juvenile passage timing at McNary Dam. We were able to determine SARs by juvenile migration timing for transported and bypassed fish.

Patterns of SARs vs. juvenile migration timing have been inconsistent for Snake River steelhead transported from Lower Granite Dam. In two of four study years (1999 and 2002), adults transported early in the juvenile migration season had low SARs, which dramatically increased for fish transported as juveniles in late April to mid-May and remained at high levels for fish transported after mid-May. In two other study years (2000-2001), transported steelhead had very high SARs though the first week in May, when all SARs plummeted to zero for the remainder of the year.

For Columbia River steelhead, the SAR pattern at McNary Dam was bimodal, with the first peak being the highest (Figure 2). The SARs of bypassed and transported groups seemed slightly out of phase, with high points in transport SARs coinciding with decreases in bypass SARs, although differences were generally small. Transport SARs were lower than those of fish bypassed early in the juvenile migration, similar to results from the Snake River.

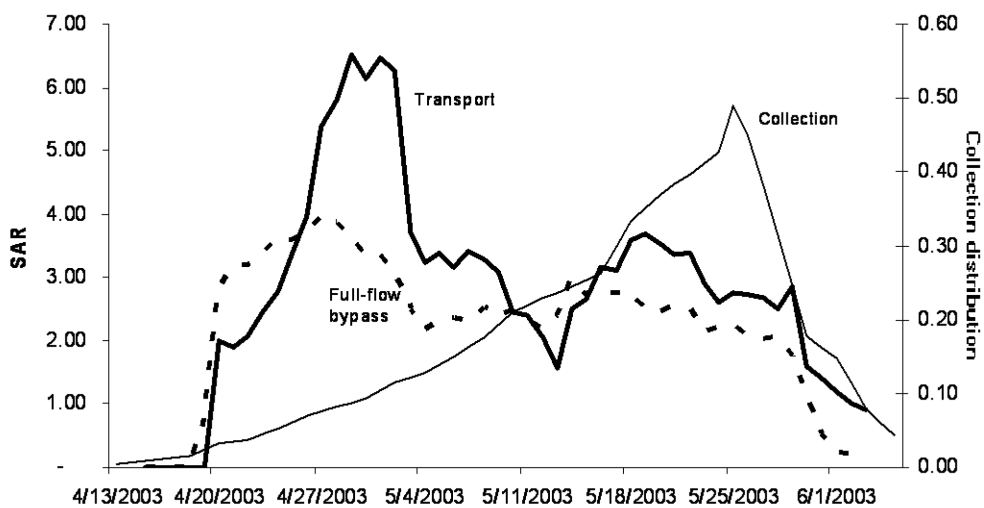


Figure 2. Smolt-to-adult return rates by juvenile detection date for steelhead smolts transported from McNary Dam compared with SARs of smolts bypassed through the McNary Dam full-flow bypass flume in 2003. Also shown is the distribution of juvenile fish collected at McNary Dam in 2003.

Delayed Mortality

Because we could not determine the relationship between SARs and juvenile migration timing for inriver migrant fish, we were unable to calculate temporal differential delayed mortality, *D*, between transported and migrant fish. We were, however, able to calculate *D* between transported and full-flow bypass fish. The pattern of seasonal variation for *D* was similar to that of SARs (Figure 3). The overall (non-weighted) *D* value for 2003 was 0.97, but varied from 0.54 to 1.60, with the highest values for fish in the latter part of the juvenile migration. The overall *D* , weighted to represent the general population of steelhead was 1.21. The difference in *D* between the non-weighted and general population was due to the later population, which had a higher *D* value, being under represented by the tagging (Figure 3).

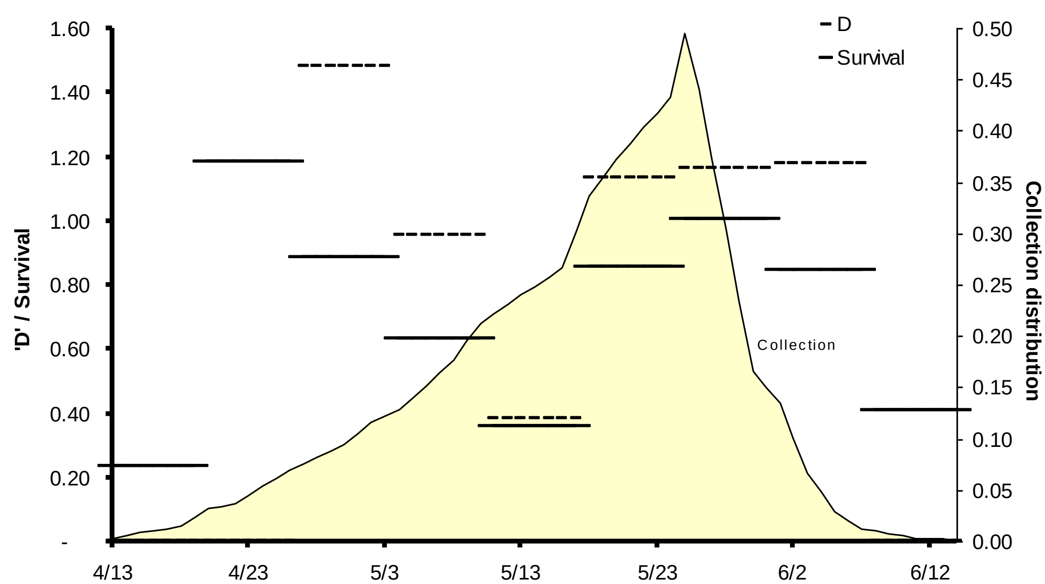


Figure 3. Estimates of differential delayed mortality *D* over time for steelhead smolts transported or bypassed from McNary Dam in 2003. Grouping is based on having adequate numbers of smolts to estimate in-river survival of bypassed fish between McNary and Bonneville Dams. Overall *D* of the tagged fish for the year was 0.97, while the overall *D* of the general population was 1.21.

Conversion Rate

The number of returning adults observed at Bonneville Dam and subsequently observed at McNary Dam (conversion rate) was similar for inriver migrant and transport groups (Table 6).

Table 6. Percentage of adult hatchery steelhead observed at Bonneville Dam that were subsequently observed at McNary Dam (the conversion rate, not adjusted for fishery) from 2003 releases.

Age class		Observed at Bonneville Dam	Observed at McNary Dam	Conversion rate
Age-1-ocean	Transport	213	156	73.24
	Full-flow bypass	194	134	69.07
	Inriver migrant	3,041	2,190	72.02
Age-2-ocean	Transport	282	196	69.50
	Full-flow bypass	301	217	72.09
	Inriver migrant	3,538	2,429	68.65
Totals	Transport	495	352	71.11
	Full-flow bypass	495	351	70.91
	Inriver migrant	6,579	4,619	70.21
All adults		7,569	5,322	70.31

Travel Time

Travel times from Bonneville to McNary Dam ranged from 11 to 19 d (Table 7). Travel times of age-2-ocean adults were 29% faster than those of age-1-ocean adults. Transported adults in both age classes were slower than bypassed and inriver migrant adults, although the difference was only 1-2.5 d.

Unlike salmon, steelhead may overwinter during their adult migration through the hydropower system, resuming migration the following spring. In the Snake River, we have noted that a significant portion of adults (up to 13%) can hold over winter and cross Lower Granite Dam the following spring, and that the majority of steelhead adults passing Lower Granite Dam in spring are from transport groups. However, for this study, only two adults from each age class (three migrants and one transport) held over and crossed McNary Dam after the first of the year.

Table 7. Median travel times from Bonneville Dam to McNary Dam for adult hatchery steelhead PIT tagged for the 2003 McNary Dam transport evaluation.

Age class		Bonneville to McNary Dam	
		Number of adults	Median travel time (d)
Age-1-ocean	Transport	156	19.0
	Bypass	134	16.5
	Migrant	2,190	17.0
Age-2-ocean	Transport	196	13.0
	Bypass	217	11.0
	Migrant	2,429	12.0
Totals	Transport	352	15.0
	Bypass	351	13.0
	Migrant	4,619	14.0

Kelts

Unlike salmon, steelhead may return to the ocean after spawning. Over the course of the study, we detected 3 kelts as they were returning to the ocean. We did not detect any kelts returning upriver to spawn for a second time.

Size at Tagging

Because the steelhead used for this evaluation were tagged 3-8 months before release, no comparisons of adult return age and tag length could be made.

DISCUSSION

Adult returns of both inriver migrant and transported steelhead from annual studies on the Snake River began increasing in the late 1990s. These larger numbers of returning adults translated to higher return rates, which allowed smaller standard errors than originally presumed for SARs. This greater precision in SARs presented us with opportunities to examine other potentially important trends, such as the relationship between timing of transportation during the juvenile migration and changes in SARs.

From transportation studies conducted on Snake River steelhead smolts since 1999, annual T/Is have shown a transport benefit overall, although the correlation between juvenile migration timing and SARs has varied (Marsh et al. 2000, 2001, 2004, 2005). In contrast to previous studies, contemporary study designs and the use of PIT tags have allowed for rigorous analysis of SARs and T/Is.

Calculating the statistics for groups of fish by the period when they were marked as smolts revealed an interesting time trend in the data. Results from the 1999 Snake River steelhead study showed annual T/Is that were lower than expected, primarily because SARs were much lower for fish tagged and transported as smolts early in the juvenile migration season than for those transported later. However, results from the 2000 and 2001 study years produced a trend that completely contradicted this pattern: that is, high SARs for fish tagged and transported early in the juvenile migration season, but very low SARs for those tagged and transported after the first 7-9 days of May.

To further confound these results, adult returns of fish tagged in 2002 were patterned similar to those of 1999: low SARs for fish tagged early in the juvenile migration season and a dramatic surge in SARs for transported juveniles tagged during the last week of April. These dichotomies in the data for adult return rates were peculiar and unexpected, and after four years of observation, the only certain conclusion with regard to juvenile migration timing vs. SARs is that we have an even split in the evidence favoring a survival advantage to early vs. late transported smolts.

A major disadvantage of the current study design for transportation evaluations is that we have no detection data with which to determine the relationship between juvenile migration timing and SARs for the inriver migrant groups. In this evaluation, we had hoped that SAR patterns in the full-flow bypass group might provide some insight into possible SAR patterns in the inriver migrant group. However, the SAR of full-flow bypass fish was considerably lower than that of the inriver migrants. Therefore, any patterns observed in the SARs of full-flow bypassed fish cannot indicate patterns in

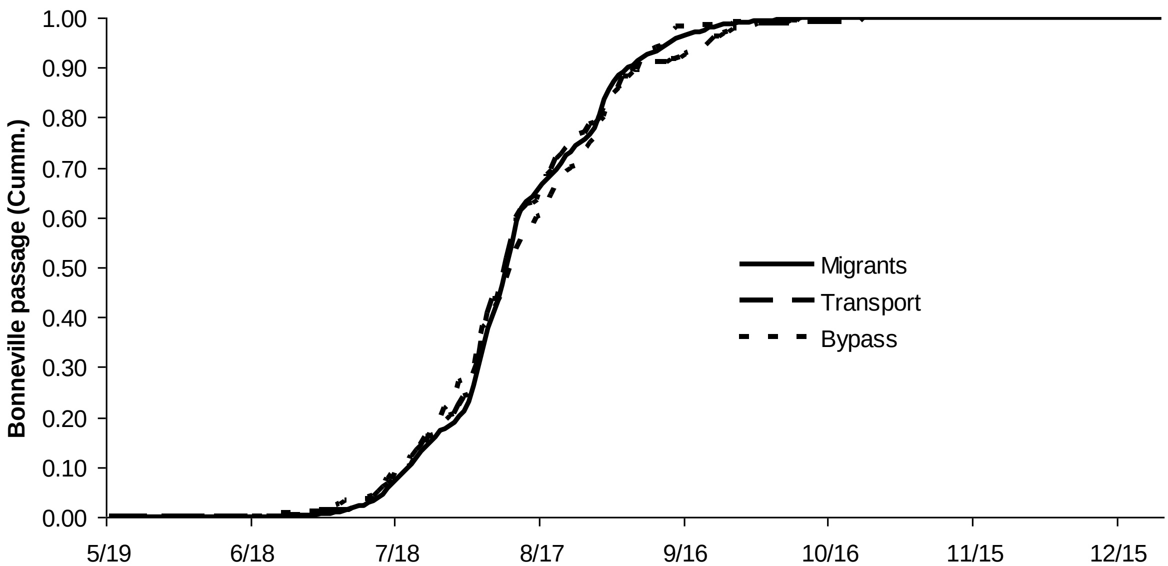
SARs for the inriver group, even though the two groups experienced identical passage conditions below McNary Dam tailrace.

There are several possible reasons why bypassed fish did not perform as well as inriver migrants. These reasons range from direct bypass-system effects to the effect of bypass on normal fish behaviors, such as schooling. Possible direct bypass system impacts could include physical or physiological impacts to the fish from the bypass route itself or from inadequate placement of the outfall pipe used to return the fish to the river.

A possible indicator as to what the problem may be comes from fish that were bypassed back to the river after having been sent over the separator. Two passage routes back to the river were utilized by fish that entered the separator (Figure 1). The first was through the adult return pipe that leads from the end of the separator to the river (and terminates closer to the shoreline than the full-flow bypass pipe). The SAR of smolts that returned to the river via this route was very low, at 0.13 (one adult from 766 juveniles).

The second alternate passage route is through the flumes and out the return-to-river pipes (which terminate at the same location as the full-flow bypass pipe). The SAR of smolts utilizing this passage route was substantially higher, at 1.51 (22 adults from 1,457 juveniles). While evaluation of these passage routes was not an objective of this study, and thus fewer smolts utilized them, we believe it will be worthwhile to examine SAR data for possible trends related to these routes in coming years.

Results from Snake River studies have indicated differences in adult arrival timing at Bonneville and Lower Granite Dams between study groups and age classes. However, results from this study show no such differences in arrival timing at either Bonneville or McNary Dams between study groups or age classes (Figures 4-5).



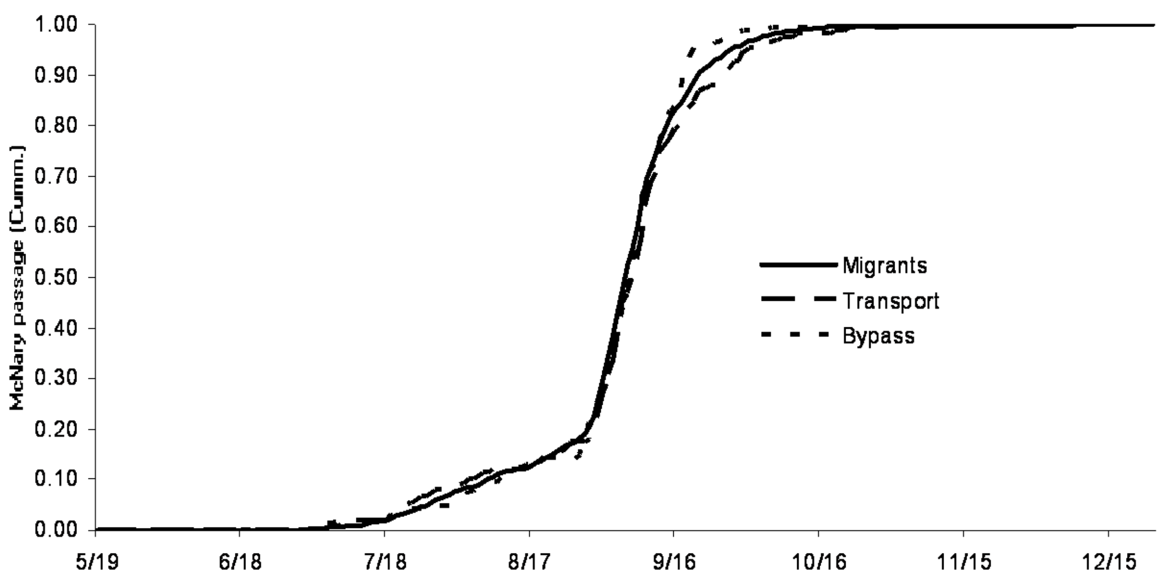


Figure 4. Distribution of age-1-ocean adult wild steelhead tagged as smolts in 2003 and detected passing Bonneville (above) and McNary Dams (below) in 2004-05.

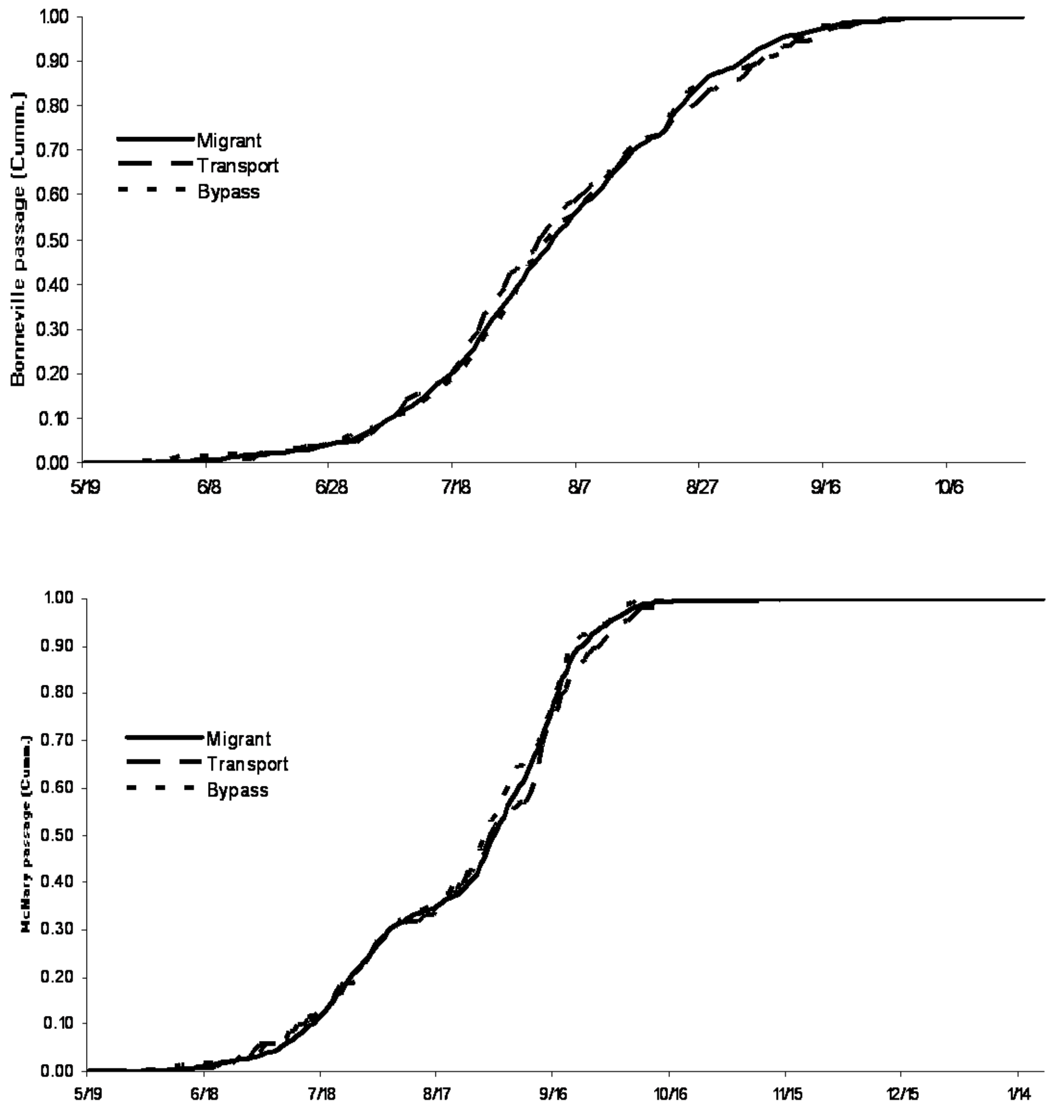


Figure 5. Distribution of age-2-ocean adult wild steelhead tagged as smolts in 2003 and detected passing Bonneville (above) and McNary Dams (below) in 2005-06.

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APPENDIX A

Juvenile Data from the 2003 Hatchery Steelhead Tagging Year

Appendix Table A1. Observations (detections), transportation, and full-flow bypass numbers at McNary Dam of hatchery steelhead released from Columbia River hatcheries above McNary Dam, 2003.

Tag group	Total observed	Number transported	Number bypassed
Winthrop	2,740	1,139	1,468
Wells	19,139	7,985	9,796
Chelan	2,462	1,141	1,195
Eastbank	5,063	2,122	2,590
Ringold	7,007	2,970	3,748
Total	36,413	15,357	18,797

Appendix Table A2. Locations of observations (detections) of PIT-tagged hatchery steelhead within the McNary Dam juvenile fish facility, 2003.

					Detected on full-flow and additional coil(s) (coil location)											
									Detected on separator and additional coil(s) (coil location)							
MCJ date	Full flow	Separator or Raceway	Bypass	Transport	Adult	Separator or Raceway	Bypass	Transport	Raceway	Bypass	Transport	Sample	Sample Bypass	Raceway	Bypass	Transport
4/13/2003	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4/14/2003	13	-	-	-	-	-	-	-	-	24	-	-	4	-	-	-
4/15/2003	34	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-
4/16/2003	3	-	-	-	-	-	-	-	-	29	-	-	1	-	-	-
4/17/2003	16	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-
4/18/2003	3	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
4/19/2003	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4/20/2003	4	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
4/21/2003	107	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
4/22/2003	167	-	-	-	-	-	-	4	-	49	642	-	43	1	-	2
4/23/2003	691	-	-	-	-	-	-	3	-	-	192	-	5	-	-	-
4/24/2003	317	-	1	-	-	2	4	1	1	3	463	1	25	-	-	2
4/25/2003	480	-	-	-	-	-	-	-	-	-	100	-	4	-	-	-
4/26/2003	100	-	-	-	-	1	-	4	2	1	210	1	2	-	1	-
4/27/2003	276	-	-	-	-	3	-	2	2	-	53	-	1	-	-	-
4/28/2003	36	-	-	-	-	-	1	-	-	1	121	-	1	-	-	-
4/29/2003	135	-	-	-	-	-	-	-	1	-	30	-	-	-	-	-
4/30/2003	46	-	-	-	-	-	-	5	-	1	142	-	-	-	-	-
5/1/2003	141	1	-	-	-	-	-	-	-	-	31	-	-	-	-	-
5/2/2003	28	-	-	-	-	-	-	-	-	-	78	-	1	-	-	-
5/3/2003	97	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-
5/4/2003	49	-	-	-	-	-	-	-	-	-	87	-	-	-	-	-
5/5/2003	125	-	-	-	-	-	-	-	-	-	38	-	-	-	-	-
5/6/2003	69	-	-	-	-	-	-	2	-	4	188	-	4	-	-	-
5/7/2003	268	-	-	-	-	-	-	-	-	-	90	-	1	-	-	1
5/8/2003	86	-	-	-	-	-	-	3	-	3	225	-	3	-	-	-
5/9/2003	400	-	-	-	-	-	-	2	1	-	68	-	1	-	-	-
5/10/2003	210	-	-	-	-	2	-	4	1	5	359	-	1	-	-	-
5/11/2003	250	-	-	-	-	1	-	-	-	-	91	-	-	-	-	-
5/12/2003	67	-	-	-	-	-	1	-	-	1	183	-	2	-	-	-

Appendix Table A2. Continued.

					Detected on full-flow and additional coil(s) (coil location)											
									Detected on separator and additional coil(s) (coil location)							
MCJ date	Full flow	Separator or Raceway	Bypass	Transport	Adult	Separator or Raceway	Bypass	Transport	Raceway	Bypass	Transport	Sample	Sample Bypass	Raceway	Bypass	Transport
5/13/2003	234	-	-	-	-	-	-	-	1	-	45	-	1	-	-	-
5/14/2003	115	-	-	-	-	-	-	-	-	1	243	-	4	-	-	-
5/15/2003	459	-	-	-	-	-	-	-	-	2	78	-	-	-	-	-
5/16/2003	328	-	-	-	-	-	-	1	-	23	611	-	6	-	-	2
5/17/2003	944	-	-	-	-	-	-	-	-	14	184	-	-	-	-	1
5/18/2003	420	-	-	-	-	-	-	2	1	66	811	-	9	-	-	1
5/19/2003	1,346	-	-	-	-	-	-	2	1	25	211	-	4	-	-	-
5/20/2003	455	-	-	-	-	-	-	4	-	92	972	-	11	-	-	7
5/21/2003	607	-	-	-	-	-	-	-	-	6	104	-	-	-	2	2
5/22/2003	237	-	-	-	-	-	-	1	-	54	489	-	5	-	-	-
5/23/2003	790	-	-	-	-	-	-	4	-	47	281	-	1	-	-	3
5/24/2003	260	-	-	-	50	-	-	1	-	104	813	-	7	-	2	-
5/25/2003	1,094	-	-	-	38	-	-	-	-	45	261	-	1	-	-	-
5/26/2003	460	-	-	1	37	1	-	24	1	137	850	1	8	-	-	1
5/27/2003	966	-	1	-	25	-	-	-	-	41	335	-	1	-	-	-
5/28/2003	357	-	-	-	2	-	-	1	2	62	570	-	6	-	-	-
5/29/2003	534	-	-	-	-	-	-	-	2	29	194	-	-	-	1	-
5/30/2003	129	-	-	-	21	-	1	-	-	30	222	-	2	-	-	-
5/31/2003	331	-	-	-	1	-	-	-	-	10	72	-	-	-	-	1
6/1/2003	225	-	-	-	163	-	-	2	2	129	1,261	-	10	-	-	2
6/2/2003	1,123	-	-	-	53	-	-	-	-	82	499	-	2	-	2	2
6/3/2003	390	1	-	-	148	-	-	-	3	35	912	1	5	-	-	1
6/4/2003	780	-	-	-	50	-	-	3	1	13	403	-	4	-	1	2
6/5/2003	360	-	-	-	61	-	1	-	-	10	320	-	7	-	-	-
6/6/2003	239	-	-	-	28	-	-	1	-	4	76	-	-	-	-	-
6/7/2003	58	-	-	-	14	-	-	1	-	-	64	-	-	-	-	-
6/8/2003	164	-	-	-	2	-	-	-	-	1	22	-	-	-	-	-
6/9/2003	118	-	-	-	19	-	-	-	1	3	117	-	-	-	-	-
6/10/2003	173	-	-	-	2	-	-	-	-	2	59	-	-	-	-	-
6/11/2003	121	-	-	-	9	-	-	-	-	2	99	-	-	-	-	-
6/12/2003	133	-	-	-	4	-	-	-	-	1	19	-	-	-	-	-

Appendix Table A2. Continued.

					Detected on full-flow and additional coil(s) (coil location)											
									Detected on separator and additional coil(s) (coil location)							
MCJ date	Full flow	Separator or Raceway	Bypass	Transport	Adult	Separator or Raceway	Bypass	Transport	Raceway	Bypass	Transport	Sample	Sample Bypass	Raceway	Bypass	Transport
6/13/2003	48	-	-	-	4	-	1	-	-	5	122	-	2	-	-	-
6/14/2003	87	-	-	-	1	-	-	-	-	4	38	-	-	-	-	-
6/15/2003	15	-	-	-	8	-	-	-	-	1	70	-	-	-	-	-
6/16/2003	81	-	-	-	4	-	-	-	-	1	26	-	-	-	-	-
6/17/2003	55	-	-	-	3	-	-	-	-	-	57	-	-	-	-	-
6/18/2003	41	-	-	-	1	-	-	-	-	1	22	-	1	-	-	1
6/19/2003	18	-	-	-	2	-	-	-	-	1	6	-	-	-	-	-
6/20/2003	15	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
6/21/2003	18	-	-	-	-	-	-	-	-	1	31	-	-	-	-	-
6/22/2003	32	-	-	-	-	-	-	-	-	-	14	-	1	-	-	-
6/23/2003	25	-	-	-	-	-	-	-	-	2	21	-	-	-	-	-
6/24/2003	34	-	-	-	-	-	-	-	-	-	17	-	-	-	-	-
6/25/2003	31	-	-	-	-	-	-	-	-	-	39	-	-	-	-	-
6/26/2003	43	-	-	-	1	-	-	-	-	-	18	-	-	-	-	1
6/27/2003	29	-	-	-	2	-	-	-	-	2	27	-	-	-	-	1
6/28/2003	1	-	-	-	1	-	-	-	-	1	32	-	-	-	-	-
6/29/2003	-	-	-	-	3	-	-	-	-	2	23	-	-	-	-	-
6/30/2003	1	-	-	-	-	-	-	-	-	1	10	-	-	-	-	-
7/1/2003	-	-	-	-	2	-	-	-	-	-	11	-	-	-	-	-
7/2/2003	2	-	-	-	-	-	-	-	-	1	5	-	-	-	-	-
7/3/2003	-	-	-	-	1	-	-	-	-	-	9	-	-	-	-	-
7/4/2003	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
7/5/2003	1	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-
7/6/2003	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
7/7/2003	-	-	-	-	1	-	-	-	-	-	3	-	-	-	-	-
7/8/2003	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
7/9/2003	-	-	-	-	1	-	-	-	-	-	5	-	-	-	-	-
7/10/2003	-	-	-	-	-	-	-	-	-	1	3	-	-	-	-	-
7/11/2003	-	-	-	-	1	-	-	-	-	1	2	-	-	-	-	-
7/12/2003	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
7/13/2003	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-

Appendix Table A2. Continued.

					Detected on full-flow and additional coil(s) (coil location)											
									Detected on separator and additional coil(s) (coil location)							
MCJ date	Full flow	Separator or Raceway	Bypass	Transport	Adult	Separator or Raceway	Bypass	Transport	Raceway	Bypass	Transport	Sample	Sample Bypass	Raceway	Bypass	Transport
7/14/2003	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
7/15/2003	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
7/16/2003	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-
7/17/2003	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7/18/2003	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
7/21/2003	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
7/22/2003	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
7/23/2003	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
7/24/2003	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-

APPENDIX B

Tagging Results for 2005 Juvenile Transportation Studies

Columbia River Hatchery Steelhead

In 2005, we continued transportation studies from McNary Dam using upper Columbia River hatchery steelhead. As in 2003 and 2004, three study groups were formed at McNary Dam; fish that were either transported, not collected, or bypassed through the primary bypass directly to the McNary Dam tailrace.

Beginning in September 2004, the U.S. Fish and Wildlife Service and Biomark, Inc. began PIT-tagging hatchery steelhead. A total of 478,854 steelhead were tagged at Winthrop (49,233), Wells (239,663), Eastbank (59,792), Chelan (34,810), and Ringold (94,875) Fish Hatcheries. In February 2005, a hole was discovered in a pond screen at Ringold Fish Hatchery. An unknown number of tagged steelhead escaped before the screen was repaired. To compensate for this, PIT tag detectors were installed on the release line from the pond, interrogating all fish leaving the pond. Those fish not detected on release have been removed from the study. This removal decreased the Ringold Fish Hatchery release number from 94,875 to 60,971.

Fish that were guided into the collection channel in McNary Dam were either bypassed directly to the river or sent into the juvenile collection facility on an every-other-day basis. The SAR of fish transported from McNary Dam will be compared to the SAR of fish bypassed directly to the river (without entering the juvenile collection facility) and to the SAR of fish that were never detected at McNary Dam.

APPENDIX C

Adult Returns from Studies in Progress

Appendix Table C1. Columbia River hatchery steelhead studies.

Tagging year	Juvenile fish numbers: Transport	Full-flow Bypass	Inriver migrant	Returns by age-class: 1-ocean	2-ocean	3-ocean	SAR: Transport	Full-flow Bypass	Inriver migrant	T T/I	B B/I	95% CI (T T/I) (B B/I)	Status	Annual report containing final results
2005	16,625	23,093	399,648	3,031	–	–	–	–	–	–	–	–	In-progress	2007
2004	12,472	14,850	447,870	1,424	1,479	–	–	–	–	–	–	–	In-progress	2006
2003*	**15,357**	**18,797**	**193,579**	**2,636**	**2,833**	**–**	**2.34**	**1.94**	**2.45**	**0.96**	**0.79**	**(0.86, 1.07)** **(0.71, 0.88)**	**Completed**	**Current**

* Juvenile numbers have been adjusted using the methods described in Appendix D.

APPENDIX D

Overview of Statistical Methodology

Estimated variance of ratio of smolt-to-adult return proportions when one of the release numbers is estimated:

From Mood et al. (1974, page 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 $R = SAR_T/SAR_{ND}$ (for transport vs. non-detected) or $R = SAR_B/SAR_{ND}$ (for bypass vs. non-detected), and using estimated values, this becomes:

$$\hat{V}(\hat{R}) \approx \hat{R}^2 \left(\frac{1}{n_T} - \frac{1}{N_T} + \frac{1}{n_{ND}} - \frac{1}{N_{ND}}\right)$$

where N_i (i = *T*, *B*, or *ND*) are numbers of juveniles and n_i are numbers of adults, since,

$$\frac{\hat{V}(S\hat{A}R_T)}{S\hat{A}R_T{}^2} = \frac{S\hat{A}R_T(1-S\hat{A}R_T)}{N_T S\hat{A}R_T{}^2} = \frac{1-S\hat{A}R_T}{N_T S\hat{A}R_T} = \frac{1}{n_T} - \frac{1}{N_T} \tag{2}$$

and similarly for SAR_B and SAR_{ND}.

If, however, N_{ND} is estimated from $NS(1-p)$ where N is the release number, S is survival from release to some location and p is probability of detection at that location, then:

$$\hat{V}(\hat{R}) \approx \hat{R}^2 \left(\frac{1}{n_T} - \frac{1}{N_T} + \frac{\hat{V}(S\hat{A}R_{ND})}{S\hat{A}R_{ND}{}^2}\right) \tag{3}$$

from (1) and (2). Now,

$$\hat{V}(S\hat{A}R_{ND}) = \hat{V}\left(\frac{n_{ND}}{N_{ND}}\right) = \hat{V}\left(\frac{n_{ND}}{N\hat{S}(1-\hat{p})}\right) = \left(\frac{1}{N^2}\right)\hat{V}\left(\frac{n_{ND}}{\hat{S}(1-\hat{p})}\right)$$

$$\approx \left(\frac{1}{N^2}\right)\left(\frac{n_{ND}}{\hat{S}(1-\hat{p})}\right)^2 \left(\frac{\hat{V}(n_{ND})}{n_{ND}{}^2} + \frac{\hat{V}(\hat{S}(1-\hat{p}))}{\hat{S}^2(1-\hat{p})^2}\right) \tag{4}$$

by (1) and,

$$S\hat{A}R_{ND}{}^2 = \left(\frac{n_{ND}}{N_{ND}}\right)^2 = \left(\frac{1}{N^2}\right)\left(\frac{n_{ND}}{\hat{S}(1-\hat{p})}\right)^2 \qquad (5)$$

So from (4) and (5),

$$\frac{\hat{V}(S\hat{A}R_{ND})}{S\hat{A}R_{ND}{}^2} \approx \frac{\hat{V}(n_{ND})}{n_{ND}{}^2} + \frac{\hat{V}(\hat{S}(1-\hat{p}))}{\hat{S}^2(1-\hat{p})^2} = \frac{1}{n_{ND}} - \frac{1}{N_{ND}} + \frac{\hat{V}(\hat{S}(1-\hat{p}))}{\hat{S}^2(1-\hat{p})^2} \qquad (6)$$

Then from (3) and (6) and substituting the estimate for N_{ND},

$$\hat{V}(\hat{R}) \approx \hat{R}^2\left(\frac{1}{n_T} - \frac{1}{N_T} + \frac{1}{n_{ND}} - \frac{1}{N\hat{S}(1-\hat{p})} + \frac{\hat{V}(\hat{S}(1-\hat{p}))}{\hat{S}^2(1-\hat{p})^2}\right) \qquad (7)$$

Now,

$$\hat{V}(\hat{S}(1-\hat{p})) \approx (1-\hat{p})^2\hat{V}(\hat{S}) + \hat{S}^2\hat{V}(\hat{p}) + 2(1-\hat{p})\hat{S}C\hat{o}v(\hat{S},1-\hat{p})$$

(Mood et al. 1974, page 180), and,

$$C\hat{o}v(\hat{S},1-\hat{p}) = -C\hat{o}v(\hat{S},\hat{p})$$

So,

$$\frac{\hat{V}(\hat{S}(1-\hat{p}))}{\hat{S}^2(1-\hat{p})^2} \approx \frac{\hat{V}(\hat{S})}{\hat{S}^2} + \frac{\hat{V}(\hat{p})}{(1-\hat{p})^2} - \frac{2C\hat{o}v(\hat{S},\hat{p})}{\hat{S}(1-\hat{p})} \qquad (8)$$

Then from (7) and (8),

$$\hat{V}(\hat{R}) \approx \hat{R}^2\left(\frac{1}{n_T} - \frac{1}{N_T} + \frac{1}{n_{ND}} - \frac{1}{N\hat{S}(1-\hat{p})} + \frac{\hat{V}(\hat{S})}{\hat{S}^2} + \frac{\hat{V}(\hat{p})}{(1-\hat{p})^2} - \frac{2C\hat{o}v(\hat{S},\hat{p})}{\hat{S}(1-\hat{p})}\right)$$

Note that *S* and p were estimated using the single-release Cormack-Jolly-Seber model (Cormack 1964; Jolly 1965; Seber 1965) using the statistical software SURPH (Skalski et al. 1993; Smith et al. 1994).