RESEARCH RELATED TO TRANSPORTATION OF JUVENILE SALMONIDS ON THE COLUMBIA AND SNAKE RIVERS, 2001

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Report of Research by

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EXECUTIVE SUMMARY

Since 1995, the U.S. Army Corps of Engineers has funded annual research by the National Marine Fisheries Service to evaluate transportation of yearling chinook salmon and steelhead smolts. During each study year, replicate groups of juvenile fish are either released to the tailrace of Lower Granite Dam to migrate in the river or transported to a release site below Bonneville Dam. Returning adults from replicates released in previous years are recovered, and ratios of adult returns from transported and inriver migrant groups are calculated.

During 2001, we continued this work and began marking subyearling chinook salmon from the Snake and Columbia Rivers to obtain contemporary transportation evaluations for these stocks. Because of expected low river flows and subsequent low survival rates for inriver-migrants, all migrants that entered juvenile collection systems at dams on the Snake River were diverted for transport. Replicate groups were released to migrate in the river only for Columbia River subyearling chinook salmon collected at McNary Dam.

For yearling chinook salmon, we PIT tagged a total of 17,710 wild smolts, releasing 17,597 into barges and/or trucks at Lower Granite Dam from 10 April to 8 June. Adult recoveries of yearling chinook tagged in 1998, 1999, and 2000 were conducted from March to August 2001 and 2002. Results are summarized below.

Year	Year		Transported			Inriver migrants		
Tagged	Recovered	Age	Hatchery	Wild	Total	Hatchery	Wild	Total
1998	2001	3	17	6	23	17	8	25
1999	2001	2	725	144	869	203	23	226
1999	2002	3	29	24	53	12	3	15

For hatchery and wild yearling chinook tagged in 1998, the transport-to-inriver (T/I) adult return ratios were 1.1 and 0.6, respectively. For all returns combined (wild and hatchery yearling chinook), T/Is were 1.0 for fish tagged in 1998 and 1.3 for fish tagged in 1999. For hatchery and wild fish tagged in 1999, T/Is were 1.3 and 1.8, respectively.

In 2000, the study design had called for tagging only wild yearling chinook and steelhead smolts and releasing them to the Lower Granite Dam tailrace. Transport groups for both species were formed from fish collected at Little Goose Dam. Sixteen yearling chinook salmon jacks were recovered from the 2000 tagging season: eight were from groups transported from Little Goose Dam, and eight were from groups released to migrate in the river and had never been detected below Lower Granite Dam.

We PIT tagged 15,984 wild steelhead smolts at Lower Granite Dam, with 15,978 released into barges or trucks from 10 April through 8 June 2001. We continued to recover age-1-ocean steelhead adults from smolts tagged in 1999 through spring 2001, and in July began recovering age-2-ocean steelhead adults tagged in 1999. Adult recoveries from steelhead smolts PIT tagged in 1998, 1999, and 2000 continued through 30 June 2002. Results are summarized below.

Year	Year		Transported fish			Inriver migrants		
Tagged	Recovered	Age	Hatchery	Wild	Total	Hatchery	Wild	Total
1998-99	2001-02	1-2	442	86	528	81	8	89
2000	2001-02	1	0	558	558	0	281	281

The T/I for steelhead marked in 1999 and recovered from 2001 to June 2002 was 1.4 for hatchery fish and 2.6 for wild fish. The overall T/I was 1.5 for all fish combined. For wild age-1-ocean steelhead adults tagged as smolts in 2000, the T/I was 1.9.

Evaluations of Snake River subyearling chinook salmon began in late spring 2001. We PIT tagged a total of 74,413 hatchery subyearling chinook at Lyons Ferry State Hatchery during 18-25 May. We released 74,245 of these fish into the Snake River above Lower Granite Dam. Of these fish, 18,907 were subsequently collected and transported from Lower Granite Dam and released below Bonneville Dam. Post-marking delayed mortality was 0.2% for the period, which ended 1 November. Of the remaining 55,338 marked subyearling chinook salmon, 9,303 were collected at downstream dams and diverted for transport using the separation-by-code system. Adult recoveries of these fish will begin in fall 2002.

Evaluations of Columbia River subyearling fall chinook salmon began on 19 June and continued through 27 July 2001. We PIT tagged a total of 62,012 subyearling fall chinook salmon collected at McNary Dam. These fish could not be identified as to hatchery or wild origin and were labeled as unknown reartype. Of the 62,012 fish tagged, 23,250 were transported and released below Bonneville Dam, while 38,546 were released into the McNary Dam tailrace to migrate in the river. Post-marking delayed mortality (24-hour) averaged 0.3% for the period. Adult recovery will begin in fall 2002.

We also continued to monitor the prevalence of marine mammal abrasions on adult spring/summer chinook salmon at Lower Granite Dam. During 2001, as in previous years, we observed a high incidence of abrasion from marine mammal teeth and claws on adult spring/summer chinook salmon sampled at Lower Granite Dam. Prevalence of abrasions was 20.9% on adults examined, with open wounds occurring on about 39% of the fish with abrasions.

CONTENTS

INTRODUCTION

Research by the National Marine Fisheries Service to evaluate the effects of transporting juvenile salmonids around dams began over 30 years ago. Evaluations of transported spring/summer chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* were conducted from various Snake River dams from 1968 through 1980. Similar studies were conducted at McNary Dam on the Columbia River from 1978 through 1983.

Results of these studies are based upon adult returns of fish marked and released as smolts, and have varied by species. Results for summer/fall (subyearling) chinook salmon and steelhead have consistently shown that significantly more transported fish returned to the point of release than did fish released to migrate inriver. However, for spring/summer chinook salmon (yearling smolts), results have been less consistent.

Results from the earliest studies, during 1968-1973, demonstrated conclusively that significantly more spring/summer chinook that were transported returned to the point of marking than did their cohorts released to migrate inriver (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980). However, most studies conducted during 1975-1980 yielded inconclusive results because very low numbers of adults returned from either group released during these years (Park 1985).

Matthews (1992) postulated that severe physical trauma suffered by many smolts during collection and marking was a primary cause of low returns of spring/summer chinook salmon adults during the 1975-1980 studies. From 1981 through 1984, the U.S. Army Corps of Engineers (COE) and fisheries agencies addressed this problem by improving many features of the smolt collection and bypass systems at dams, particularly at Lower Granite Dam. In addition, the preanesthetic system of handling and marking smolts was introduced at Lower Granite Dam in 1983 (Matthews et al. 1997). This system virtually eliminated the major physical trauma associated with the handling and marking process. All indications suggest that these modifications and improvements substantially increased survival.

In 1986, a study was initiated at Lower Granite Dam to reevaluate smolt transportation of yearling chinook salmon migrants from the Snake River after substantial modifications were made to collection and bypass facilities. Spring/summer chinook salmon smolts were marked with coded-wire tags (CWT) and freeze brands in 1986 and 1989 at Lower Granite Dam. Approximately one-half of the marked smolts were placed in barges at Lower Granite Dam, and the remainder were trucked to a release site downstream from Little Goose Dam to continue their inriver migration.

Although significantly more barged fish returned as adults than those that migrated inriver, concern was expressed that the studies were compromised by transporting the inriver migrant fish to a release location below Little Goose Dam

(Ward et al. 1997). The studies were further criticized because a small fraction of inriver-migrating fish were inadvertently transported from McNary Dam and because river conditions at the time of these studies were not considered optimal for migration. Thus, it was argued, the inriver-migrating fish were not afforded the full opportunity to migrate in the river at the highest possible survival rates.

In 1995, new transport studies began using PIT-tagged fish. As a result of PIT-tag detectors installed at most lower Snake and Columbia River dams, and slide gates that can divert detected PIT-tagged fish to transport barges or back to the river, the use of PIT tags allows us to identify the individual migration history of each fish (Prentice et al. 1990, 1999; Matthews et al. 1990, 1992; Achord et al. 1992; Harmon et al. 1995; Marsh et al. 1999). We can track which fish are transported and compare adult returns of transported fish to adult returns from fish with various inriver migration histories.

To date, smolt-to-adult returns (SARs) for inriver-migrating, PIT-tagged fish have varied based on detection histories. In general, PIT-tagged fish not detected at collection/transportation dams have returned at rates greater than fish detected at those dams. Further, these non-detected PIT-tagged fish are the best reference group for the transported fish because all non-tagged fish collected at lower Snake River dams are transported. Thus, concern exists that reference fish in our recent studies were not representative of the population of in-river migrants. In 2000, we therefore increased the number of fish released to migrate in river to assure that more fish in the non-detected category were available for comparison.

The primary objective of our studies is to compare adult returns between chinook salmon and steelhead PIT-tagged as smolts and transported to a release site below Bonneville Dam to those allowed to migrate inriver under optimal conditions for inriver survival. Detections from PIT-tagged smolts released to migrate inriver will also provide data for short-term survival estimates between the Lower Granite and Bonneville Dam tailraces using the Single-Release Model (Iwamoto et al. 1994, Smith et al. 1999).

Here we report tagging results and other data from our study fish during the 2001 juvenile migrations, and adult return data from fish tagged as smolts in 1998, 1999, and 2000. As in previous years, we examined returning adults for evidence of marine mammal tooth and claw marks and we report the incidence of these abrasions.

Finally, we began a study at McNary Dam to gather contemporary data on the efficacy of transporting fall chinook salmon through the lower Columbia River dams.

SNAKE RIVER SPRING/SUMMER CHINOOK SALMON AND STEELHEAD

Methods

Juveniles

Because of the low river flows and expected low survival for inriver migrants in the Snake River, no water was spilled during 2001 at the three Snake River collector dams. This allowed the maximum number of fish to be collected from the bypass systems for transportation. For both spring/summer chinook salmon and steelhead, we marked only transport index groups at Lower Granite Dam. No tagged fish were released into the Lower Granite Dam tailrace; therefore, no inriver migration data from the 2001 migration were generated for spring/summer chinook salmon or steelhead.

The number of PIT-tagged fish required for a transport index group at Lower Granite Dam was expressed as

$$N = (2\alpha/2)^2 \times SAR \times (1\text{-}SAR)/w^2$$

where N is the number of PIT-tagged juveniles required for a transport index group, SAR is the expected smolt-to-adult return rate, and *w* is one-half the width of a 95% confidence interval for the SAR.

We set $\alpha = 0.05$, and *w* at 0.002 (0.2%), and we assumed an SAR for transported fish of 0.01 (1.0%). This produced N = 10,000; therefore, we proposed to tag a minimum of 10,000 fish of each species for the transport index groups in spring 2001. Basic collection and handling of juveniles followed the methodology described by Marsh et al. (1996, 2001). We continued using the recirculating anesthetic water system described by Marsh et al. (2001).

Adult Recoveries and Data Analysis

In 2001, adult fish PIT-tagged as juveniles for our studies in 1998 through 2000 were detected in the fish ladders of Bonneville and Lower Granite Dams.

To analyze differences in SARs, we used data analysis procedures described by Marsh et al. (1996), but we modified these procedures to account for different passage histories, as described by Sandford and Smith (2002). This required adjusting the observed numbers of fish detected and transported, bypassed at downstream dams, or not detected at all for estimated bias associated with mortality between dams. This method apportions the number of fish released at Lower Granite Dam into various downstream detection-history categories based on estimated detection percentages at the downstream dams. Thus, during the present studies, the inriver control group was composed of those smolts not detected at one of the collector dams on the Snake River below Lower Granite Dam.

To calculate 95% CIs for various transport to inriver ratios (T/Is), release days were pooled until a minimum of two adults returned in both transport and in-river categories. Empirical variance estimates were calculated using these temporal replicates. Daily (or multiple-day pooled) facility collection numbers were used to weight the replicates to provide weighted seasonal T/Is applicable to the untagged population. The weighted mean T/Is and CIs were then constructed on the natural logarithm scale (i.e., such ratio data were assumed log-normally distributed) and back-transformed.

We continued to examine the relationships between SARs and/or T/Is, and release date and/or total river flow, using linear regression techniques.

Results

Juveniles

We PIT tagged fish from 10 April through 8 June 2001. During this period, we tagged 17,610 wild yearling chinook salmon and 15,982 wild steelhead (Appendix Table 1). The number of chinook salmon tagged daily ranged from 14 to 1,108. Of the 17,610 wild yearling spring/summer chinook salmon tagged, 17,597 were released into barges at Lower Granite Dam. The number of steelhead tagged daily ranged from 2 to 1,833. Of the 15,982 wild steelhead tagged, 15,978 were loaded into barges at Lower Granite Dam.

	Number tagged	Number released	Mean fork length (mm)
Spring/summer chinook	17,610	17,597	111.7
Steelhead	15,982	15,978	183.3

All tagged fish were held in facility raceways for at least 24 hours before loading into a barge. Because of the size of the raceways in which the fish were held, we were unable to adequately sample for mortalities; therefore, we did not measure post-marking delayed mortality (24-hour) in 2001.

We recorded fork lengths of all fish during tagging. During the course of tagging, we encountered spring/summer chinook salmon that were obviously of hatchery origin, but had partial or no fin clips. In 1996, we also observed this problem and investigated whether fork length could be used as an indicator of wild or hatchery origin. An analysis by Marsh et al. (1997) showed that few wild fish had fork lengths that exceeded 123 mm.

After a reevaluation, we set a maximum fork length of 124 mm for wild fish during the 2001 juvenile migration. Fish that had adipose fins and were larger than 124 mm were considered of hatchery origin and were not tagged. We used a simple measuring device to separate fish by length at the sorting troughs. Over the course of the season, only 51 spring/summer chinook salmon smolts greater than 124 mm were inadvertently tagged as wild fish (0.03% of the smolts handled).

Adult Recoveries and Data Analysis

Spring/Summer Chinook Salmon–At Lower Granite Dam, we recovered age-3-ocean adult spring/summer chinook salmon from the 1998 study year (Table 1). The first adult arrived at the dam on 13 April and the last arrived on 20 July.

In total, we recovered 66 age-3-ocean adults during 2001, bringing the total returns from the 1998 tagging to 558 fish. However, we eliminated eight fish from the analysis for a variety of reasons including PIT tags that were not recorded at tagging and fish that were designated as inriver study fish but were transported at dams downstream from Lower Granite Dam. We eliminated 109 fish from the analysis because they had been detected and returned to the river at one or more dams downstream from Lower Granite Dam. Of the remaining 441 adult spring/summer chinook salmon, 280 were from transport releases (246 hatchery and 34 wild), and 161 were from inriver migrant releases (133 hatchery and 28 wild).

Overall, SARs were 0.62% for transported fish and 0.61% for inriver fish, for an overall T/I of 1.0 (95% CI 0.9, 1.2) for fish transported from Lower Granite Dam. When we weighted the seasonal T/Is to collection distribution of the untagged population, the T/I for fish released through 3 May was 1.1 (95% CI 0.6, 2.0). For fish released after that date, the T/I was 2.5 (a 95% CI could not be determined).

Hatchery and wild fish accounted for 81.6 and 18.4% of the returning adults, respectively. Percentages of hatchery and wild fish tagged as smolts were 80.5 and 19.5%, respectively (Marsh et al. 2000), although the wild fraction was bolstered to some extent because some small juvenile hatchery fish were not adipose-fin clipped and were inadvertently counted as wild during marking. The SARs for transported spring/summer chinook salmon were 0.62% for hatchery fish and 0.60% for wild fish; SARs for inriver migrating chinook salmon were 0.57% for hatchery fish and 0.95% for wild fish. The respective T/Is for hatchery and wild fish were 1.1 (95% CI 1.0, 1.3) and 0.6 (95% CI 0.4, 0.9) for chinook salmon transported from Lower Granite Dam in 1998.

Table 1. Adult spring/summer chinook salmon marked at Lower Granite Dam in 1998 and recovered through 17 August 2001. The inriver group includes only fish not detected during their juvenile migration at a Snake River collector dam after release into the Lower Granite Dam tailrace. All PIT-tag recoveries above Lower Granite Dam are included.

		Adult returns at Lower Granite Dam		PIT-tag recoveries			
Group[a]	Number released	Number	%	Hatcheries	Sports fishery	Spawning grounds	Traps
Transported							
Hatchery	39,596	245	0.62	7	0	0	4
Wild	5,689	34	0.60	0	0	0	0
Total	45,285	279	0.62	7	0	0	4
Inriver[b]							
Hatchery	23,552	134	0.57	6	0	0	4
Wild	2,932	28	0.95	0	0	0	0
Total	26,425	162	0.61	6	0	0	4

[a] Based upon fin clips, fish were classified as hatchery, wild, or unknown when tagged as juveniles. However, many fish were likely mis-classified because high numbers of hatchery fish were poorly fin clipped or received no fin clips (see Marsh et al. 1997).

[b] Numbers adjusted as described in Sandford and Smith (2001).

For the 1998 study year, SARs of both study groups varied considerably through time (Fig. 1). During most of April, T/Is were less than 1.0, while during most of May, they were generally 2.0 or greater due primarily to the abrupt increase in transport SARs near the end of April.

To examine the relationship between river discharge and survival for spring/summer chinook salmon tagged in 1998, we regressed flows measured at Lower Monumental Dam against SARs of inriver fish (Fig. 2) and flows measured at Bonneville Dam against SARs of transported fish (Fig. 3). For inriver fish, there was a significant negative relationship between the flow levels encountered and SARs (i.e., SARs were lower when flows were higher). There was no relationship between the flow levels encountered in the lower Columbia River and SARs of transported fish.

For all adult returns from the 1998 marking, 39 transported fish (33 hatchery and 6 wild) and 14 inriver migrants (12 hatchery and 2 wild) were observed on detection coils in the Adult Fish Facility (AFF) at Bonneville Dam. Of these adults, 28 transported (22 hatchery and 6 wild) and 10 inriver migrant fish (8 hatchery and 2 wild) were detected passing Lower Granite Dam. For transported and inriver migrant fish combined, detection rates at Lower Granite Dam of adults previously detected at Bonneville Dam were 66.6% for hatchery fish and 100% for wild fish. For wild and hatchery fish combined, detection rates at Lower Granite Dam were equal for transported and inriver migrant fish previously detected at Bonneville Dam, indicating no differential homing to Lower Granite Dam for either wild or hatchery fish.

Prior to release back to the ladder, we examined each adult for marks and injuries and recorded its fork length. We are beginning to receive information regarding upstream recoveries of the study fish.

From March 2001 through August 2002, we also recovered age-2-ocean and age-3-ocean spring/summer chinook salmon tagged as smolts at Lower Granite Dam in 1999 (Table 2). The first adult in 2001 was observed at the dam on 10 April and the last on 9 August. The first adult in 2002 was observed at the dam on 26 April and the last on 21 July.

Total returns from the 1999 tagging were 2,008 fish. However, we eliminated 750 fish from the analysis for a variety of reasons including fish that had unrecorded PIT tags at tagging and inriver study fish that were transported at dams downstream from Lower Granite Dam. Of the remaining 1,258 adults in the study, 1,010 were from transported groups (834 hatchery and 176 wild) and 248 (225 hatchery and 23 wild) were from inriver migrant groups. Overall SARs to Lower Granite Dam were 1.99% for transported fish and 1.51% for inriver fish, for an overall T/I of 1.3 (95% CI 1.2, 1.4).

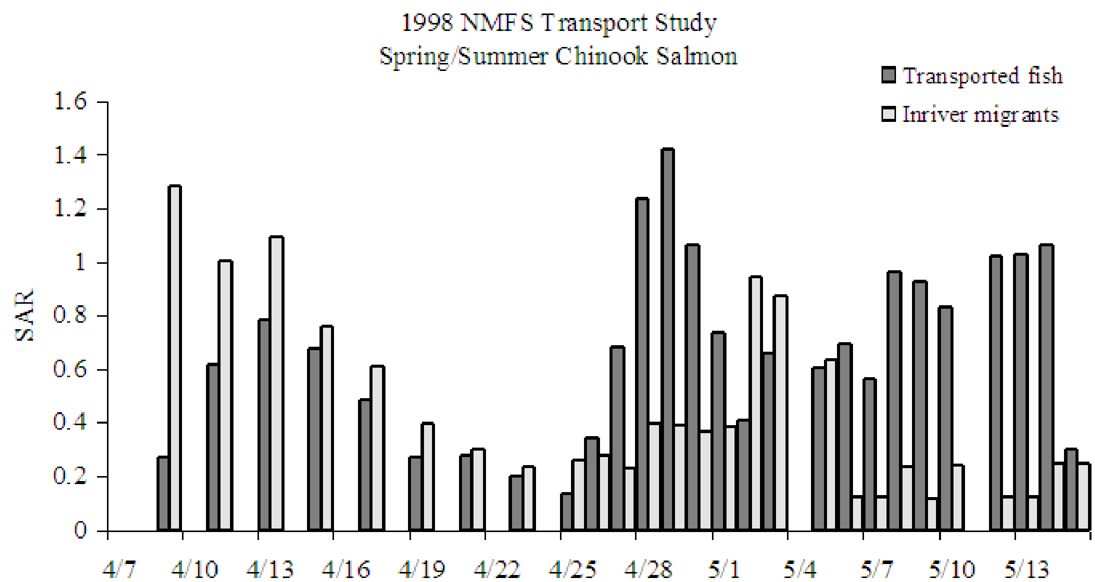

Figure 1. Smolt-to-adult return ratios (SARs) for transported and inriver migrant spring/summer chinook salmon smolts tagged at Lower Granite Dam in 1998. Data presented as 3-day running averages of daily releases.

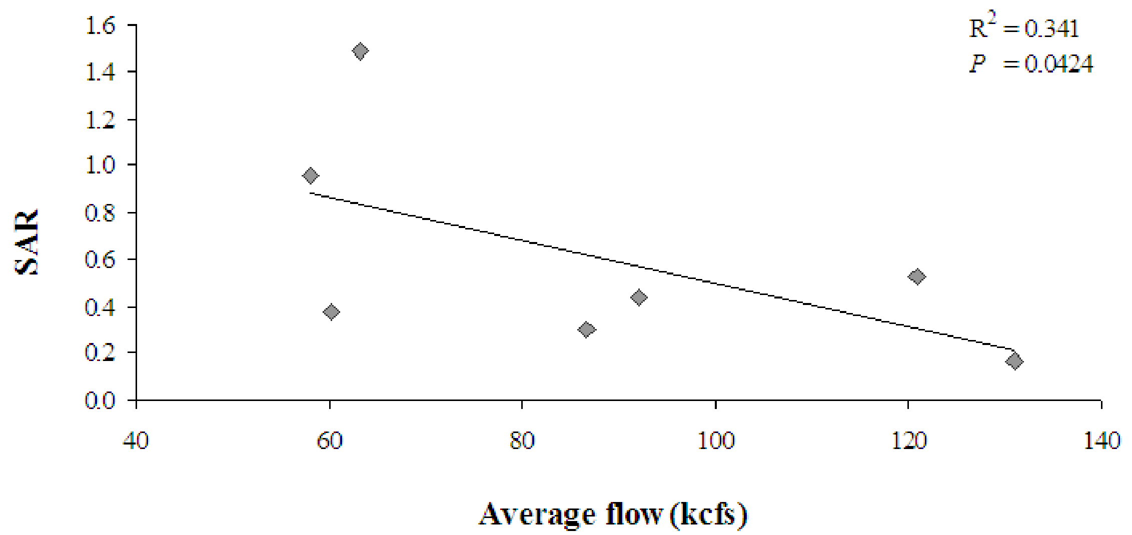

Figure 2. Spring/summer chinook salmon inriver SARs vs. Snake River flow measured at Lower Monumental Dam in spring 1998.

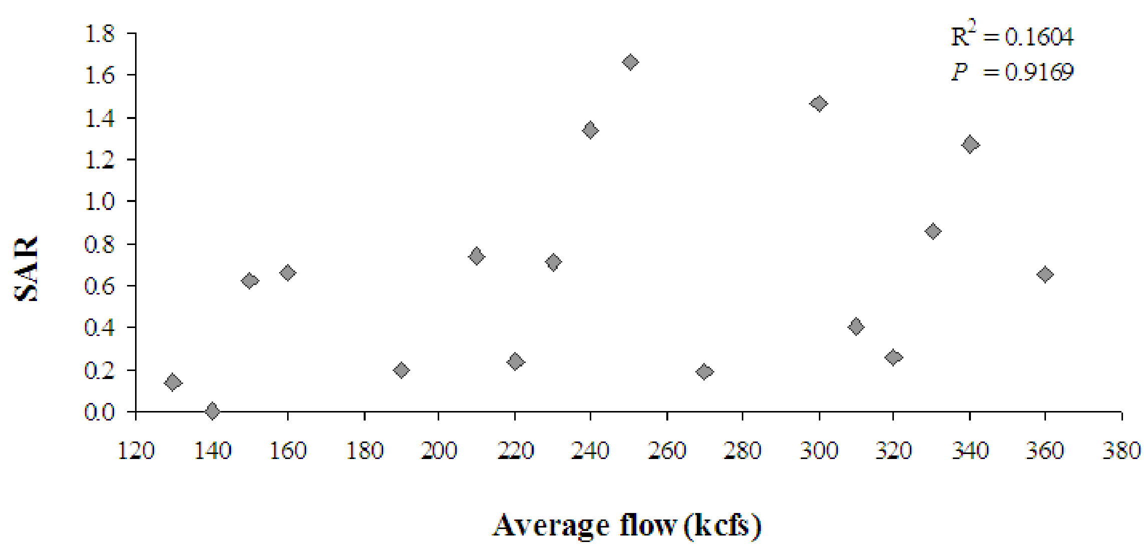

Figure 3. Spring/summer chinook salmon transport SARs vs. Columbia River flow measured at Bonneville Dam in spring 1998.

Table 2. Adult spring/summer chinook salmon marked at Lower Granite Dam in 1999 and recovered through 17 August 2002. The inriver migrant group includes only fish not detected during their juvenile migration at a Snake River collector dam after release into the Lower Granite Dam tailrace. All PIT-tag recoveries above Lower Granite Dam are listed.

		Adult returns at Lower Granite Dam		PIT-tag recoveries			
Group[a]	Number released	Number	%	Hatcheries	Sports fishery	Spawning grounds	Traps
Transported fish							
Hatchery	43,575	834	1.91	6	0	1	28
Wild	8,556	176	2.06	0	0	1	1
Total	52,131	1,010	1.94	6	0	2	29
Inriver migrants[b]							
Hatchery	15,682	225	1.43	3	0	0	6
Wild	1,991	23	1.16	0	0	0	1
Total	17,673	248	1.40	3	0	0	7

a Based upon fin clips, fish were classified as hatchery, wild, or unknown when tagged as juveniles. However, many fish were likely mis-classified because high numbers of hatchery fish were poorly fin clipped or received no fin clips (see Marsh et al. 1997).

b Adjusted as described in Sandford and Smith (2001).

During winter 2000-2001, PIT-tag detection coils were installed in the Washington Shore Ladder of Bonneville Dam. With the new coils, the 134.2-kHz PIT tags implanted in our study fish in 2000 were readable. Thus, fish returning from our 2000 marking program were detectable by coils in both the AFF and the Washington Shore Ladder. During their return, 10 jacks (4 transported fish and 6 inriver migrants) were observed on detection coils in the Bonneville Washington Shore Ladder or in the AFF. All of these fish successfully migrated from Bonneville to Lower Granite Dam.

Steelhead–In spring 2001, we continued to recover age-1-ocean steelhead tagged as smolts in 1999 and, in summer 2001, began recovering age-2-ocean steelhead tagged as smolts in 1999 (Table 3). The last age-1-ocean steelhead returned on 12 May 2001. The first age-2-ocean steelhead adult returned on 1 July, and the last was recovered on 12 December. We continued collecting age-2-ocean steelhead through 30 June 2002. The first spring recovery was on 14 March and the last was on 14 April.

Hatchery and wild fish accounted for 83.4 and 16.6% of the returning adults, respectively. Percentages of hatchery and wild fish tagged as smolts were 80.5 and 19.5%, respectively (Marsh et al. 2000), although the wild fraction was bolstered to some extent because some small hatchery fish were not adipose-fin clipped when marked as juveniles and were counted as wild. Transport SARs were 1.91% for hatchery fish and 2.06% for wild fish, while SARs for the inriver fish were 1.43% for hatchery fish and 1.16% for wild fish. The respective T/Is for hatchery and wild fish were 1.3 (95% CI 1.2, 1.4) and 1.6 (95% CI 1.2, 2.2) for fish transported from Lower Granite Dam. Similar to the 1998 study year, SARs of both study groups varied considerably through time in 1999 (Fig. 4).

To examine the relationship between river discharge and survival for spring/summer chinook salmon tagged in 1999, we regressed flows measured at Lower Monumental Dam against SARs of inriver fish (Fig. 5) and flows measured at Bonneville Dam against SARs of transported fish (Fig. 6). There was no relationship between SARs and the flow levels encountered in either comparison.

For all adults returning from the 1999 marking effort, totals of 318 transport adults (264 hatchery and 54 wild) and 55 inriver adults (52 hatchery and 3 wild) were observed on detection coils in the AFF at Bonneville Dam. Of these adults, 221 transported fish (181 hatchery and 40 wild) and 39 inriver migrants (37 hatchery and 2 wild) were detected passing Lower Granite Dam. Conversion rates between the two dams were 68.6% for transported hatchery fish, 71.2% for inriver hatchery fish, 74.1% for transported wild fish, and 66.6% for inriver wild fish. Again, nearly equal conversion rates suggest no homing problems for transported fish.

Prior to release back to the ladder, we examined each adult for marks and injuries and recorded its fork length.

Table 3. Adult steelhead marked as juveniles at Lower Granite Dam in 1999 and recovered through 30 June 2002. The inriver migrant group includes only fish not detected during their juvenile migration at a Snake River collector dam after release into the Lower Granite Dam tailrace.

		Adult returns at Lower Granite Dam	
Group[a]	Number released	Number	%
Transported fish			
Hatchery	41,109	442	1.08
Wild	6,062	86	1.42
Total	47,171	528	1.12
Inriver migrants[b]			
Hatchery	10,442	81	0.78
Wild	1,471	8	0.54
Total	11,913	89	0.75

[a] Based upon fin clips, fish were classified as hatchery, wild, or unknown when tagged as juveniles. However, many fish were likely mis-classified because high numbers of hatchery fish were poorly fin clipped or received no fin clips (see Marsh et al. 1997).

[b] Numbers adjusted as described in Sandford and Smith (2001).

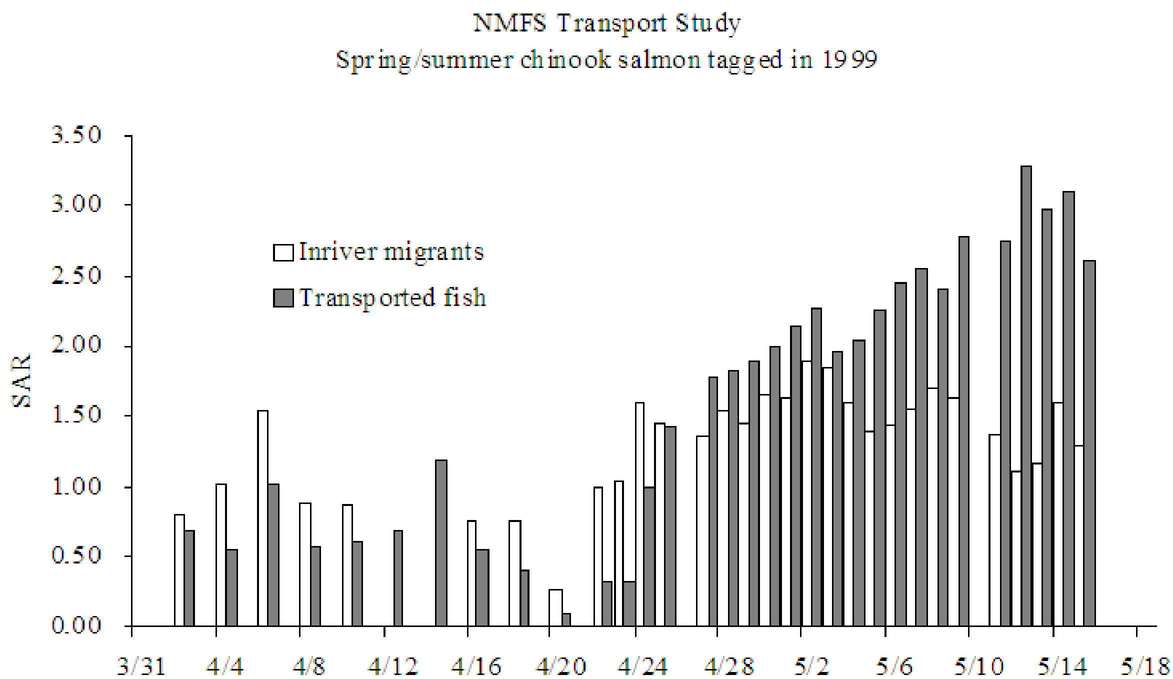

Figure 4. SARs for transported and inriver migrant spring/summer chinook salmon smolts tagged at Lower Granite Dam in 1999. Data presented as 3-day running averages of daily releases and juvenile releases.

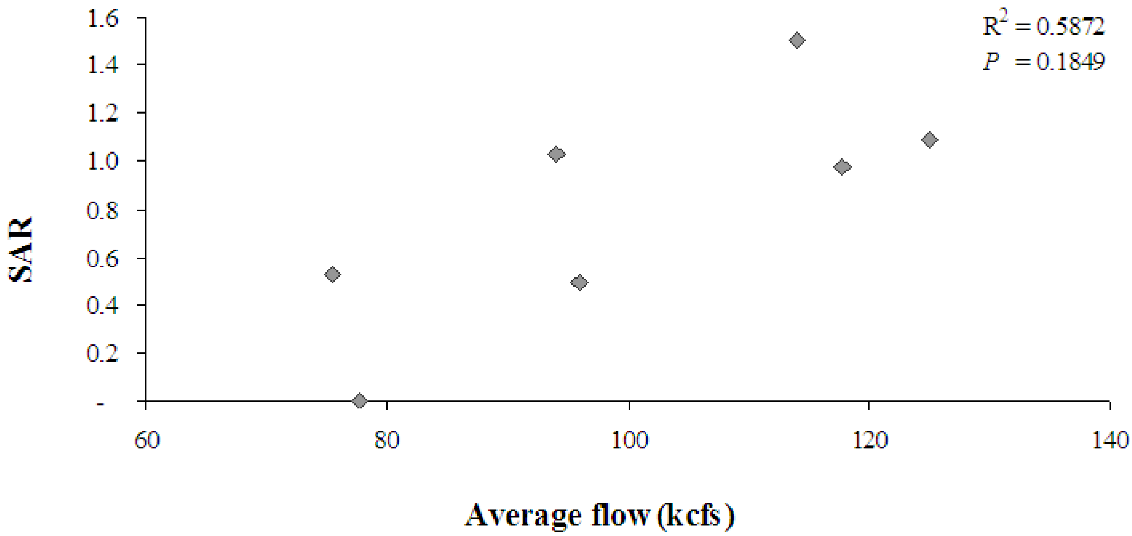

Figure 5. Spring/summer chinook salmon inriver SARs vs. Snake River flow measured at Lower Monumental Dam in spring 1999.

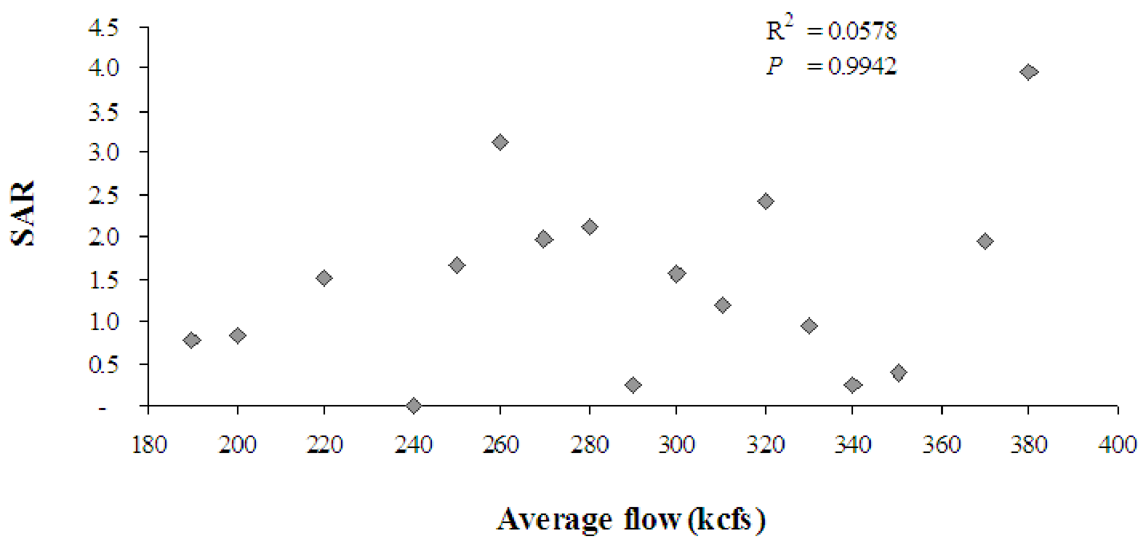

Figure 6. Spring/summer chinook salmon transport SARs vs. Columbia River flow measured at Bonneville Dam in spring 1999.

We adjusted the study design for the 2000 smolt migration (Marsh et al. 2001). One major change was the marking of wild fish only. At Lower Granite Dam in 2001, we recovered 30 wild spring/summer chinook salmon jacks tagged as smolts at the dam in 2000 (Table 4). The first jack was observed on 11 May and the last on 22 July. Of the 30 fish, 14 were removed from the analysis because they were detected at a dam downstream from Lower Granite Dam but were not transported from Little Goose Dam. Of the remaining jacks, eight were transported fish and eight were inriver migrants. SARs to Lower Granite Dam were 0.05% for the group transported from Little Goose Dam and 0.03% for inriver fish, for an overall T/I of 1.7. A 95% CI will be calculated when adult returns are complete.

So far, we have recovered 969 steelhead adults tagged as smolts in 1999. Of the 969 adults, 352 (297 hatchery and 55 wild) were removed from the analysis for a variety of reasons, including that they were inriver study fish that were transported from dams downstream from Lower Granite Dam. Of the remaining 617 adults, 528 (442 hatchery and 86 wild) and 89 (81 hatchery and 8 wild) were from the transport and inriver releases, respectively. Overall, SARs to Lower Granite Dam were 1.12% for the group transported from the dam and 0.75% for the inriver group, for an overall T/I of 1.5. A 95% CI will be calculated when adult returns are complete.

Hatchery and wild fish accounted for 84.6 and 15.4% of the returning steelhead adults, respectively. When tagged as smolts, the percentages of hatchery and wild fish tagged were 87.5 and 12.5%, respectively (Harmon et al. 2000), although the wild fraction was bolstered to some extent because some small juvenile hatchery fish were not adipose-fin clipped and were counted as wild during marking. The SARs were 1.08% for transported hatchery fish and 1.42% for transported wild fish. For inriver migrants, SARs were 0.78% for hatchery fish and 0.54% for wild fish. The respective T/Is for hatchery and wild fish were 1.4 and 2.6 for fish transported from Lower Granite Dam.

For steelhead smolts tagged in 1999, the adult returns from both study groups followed the same temporal patterns as previously noted above for spring/summer chinook salmon tagged in the same year (Fig. 7).

To examine the relationship between river discharge and survival for steelhead smolts tagged in 1999, we regressed flows measured at Lower Monumental Dam against SARs of inriver fish (Fig. 8) and flows measured at Bonneville Dam against SARs of transported fish (Fig. 9). There was no relationship between SARs and the flow levels encountered for either study group in 1999.

Table 4. Adult wild spring/summer chinook salmon marked at Lower Granite Dam in 2000 and recovered through 17 August 2001. The inriver migrant group includes only fish that were never detected during their juvenile migration at a Snake River collector dam after release into the Lower Granite Dam tailrace. All PIT-tag recoveries above Lower Granite Dam are listed.

		Adult returns at Lower Granite Dam		PIT-tag recoveries			
Group[a]	Number released	Number	%	Hatcheries	Sports fishery	Spawning grounds	Traps
Transported fish	15,835	8	0.05	0	0	0	0
Inriver migrants	26,340	8	0.03	0	0	0	0

[a] Numbers adjusted as described in Sandford and Smith (2001).

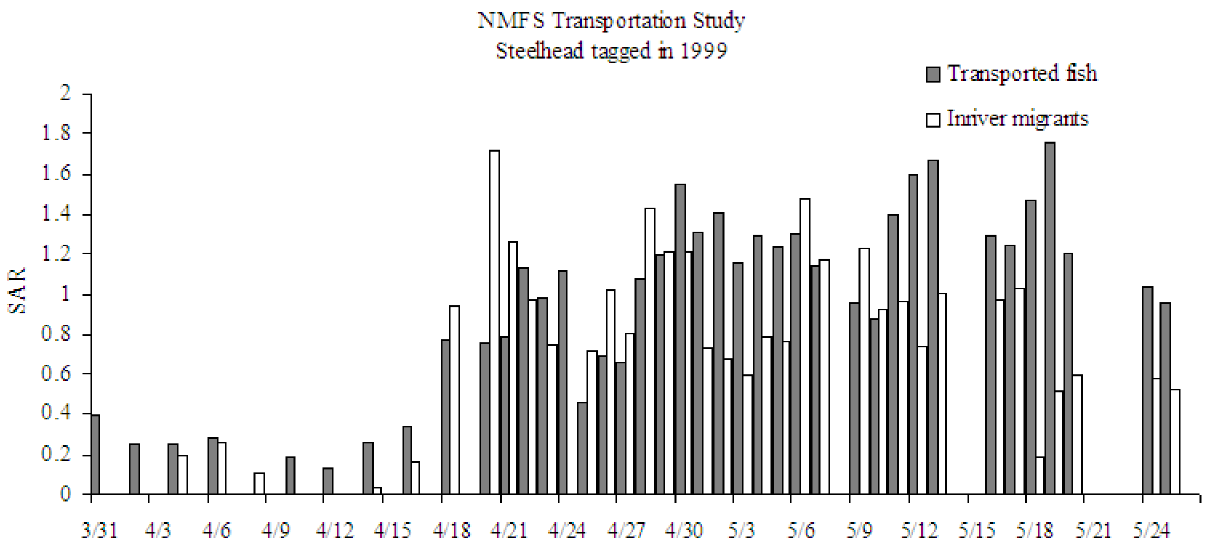

Figure 7. SARs for transported and inriver migrant steelhead smolts tagged at Lower Granite Dam in 1999. Data presented as 3-day running averages of daily releases and juvenile releases.

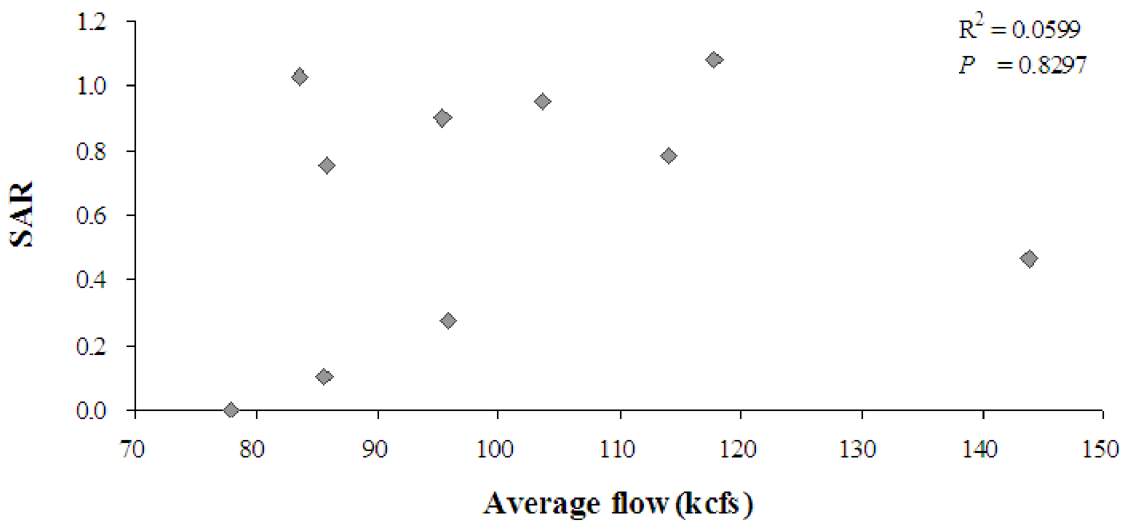

Figure 8. Smolt-to-adult return (SAR) rates for inriver migrant steelhead vs. Snake River flow measured at Lower Monumental Dam in spring 1999.

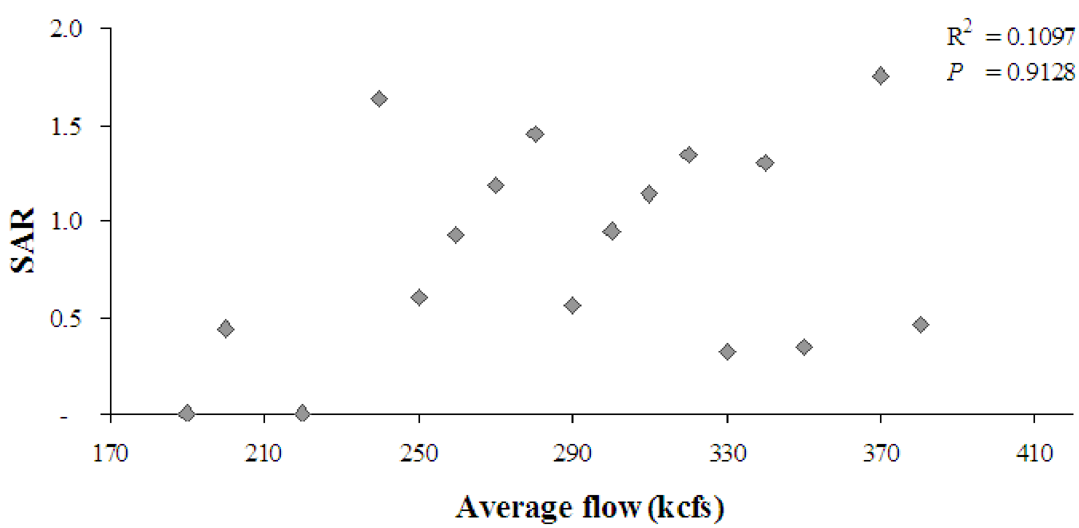

Figure 9. Smolt-to-adult return (SAR) rates for inriver migrant steelhead vs. Columbia River flow measured at Bonneville Dam in spring 1999.

For all adult returns from the 1999 marking, 210 transport adults (172 hatchery and 38 wild) and 36 inriver adults (33 hatchery and 3 wild) were observed on detection coils in the AFF at Bonneville Dam. Of these adults, 79 transport adults (64 hatchery and 15 wild) and 16 inriver adults (15 hatchery and 1 wild) were detected passing Lower Granite Dam. Conversion rates between the two dams will be calculated for steelhead only when adult returns for a study are complete.

Prior to release back to the ladder, we examined each adult for marks and injuries and recorded its fork length. We are beginning to receive information regarding upstream recoveries of these study fish. As mentioned above, only wild fish were marked in 2000. At Lower Granite Dam in 2001, we recovered 1,088 wild age-1-ocean steelhead adults tagged as smolts at the dam in 2000, with preliminary SARs ranging from 1.19 (inriver fish) to 2.26 (transported fish). Recoveries through 30 June 2002 are summarized below.

	Smolts released	Adults recovered	SAR
Transported fish	22,265	558	2.26
Inriver migrants	23,516	281	1.19

The inriver migrant group included only fish not detected during their juvenile migration at a Snake River collector dam after release into the Lower Granite Dam tailrace. Adjusted numbers for inriver migrants are described by Sandford and Smith (2001).

A 95% confidence interval for the SAR will be calculated when adult returns are complete. The first adult was observed on 5 July, and the last was recovered on 12 December. We continued collecting age-1-ocean steelhead through spring 2002, with the first one observed on 10 March and the last one observed on 29 June.

For the first time since tagging began in 1995 for the current series of studies, SARs for wild steelhead smolts transported in 2000 did not exhibit the same early dynamics as was observed for each previous study year (Fig. 10). Unlike previous studies when the highest transport SARs were recorded after the first week in May, no transported fish returned for smolts tagged and transported after this time in 2000. The SAR pattern for inriver study fish was similar, although SARs for these fish began to decline near the beginning of May. As for transported fish, only a trivial number of inriver fish returned from smolts tagged after 8 May. For both study groups combined, only 1.0% of the adult returns were from fish marked after 8 May, even though 21.0% of the juveniles were marked after that date.

To examine the relationship between river discharge and survival for steelhead smolts tagged in 2000, we regressed flows measured at Lower Monumental Dam against SARs of inriver fish (Fig. 11) and flows measured at Bonneville Dam against SARs of transported fish (Fig. 12). While there was no relationship between inriver SARs and flows at Lower Monumental Dam, there was a significant negative relationship between transport SARs and Bonneville Dam flows (i.e., SARs decreased as flows increased).

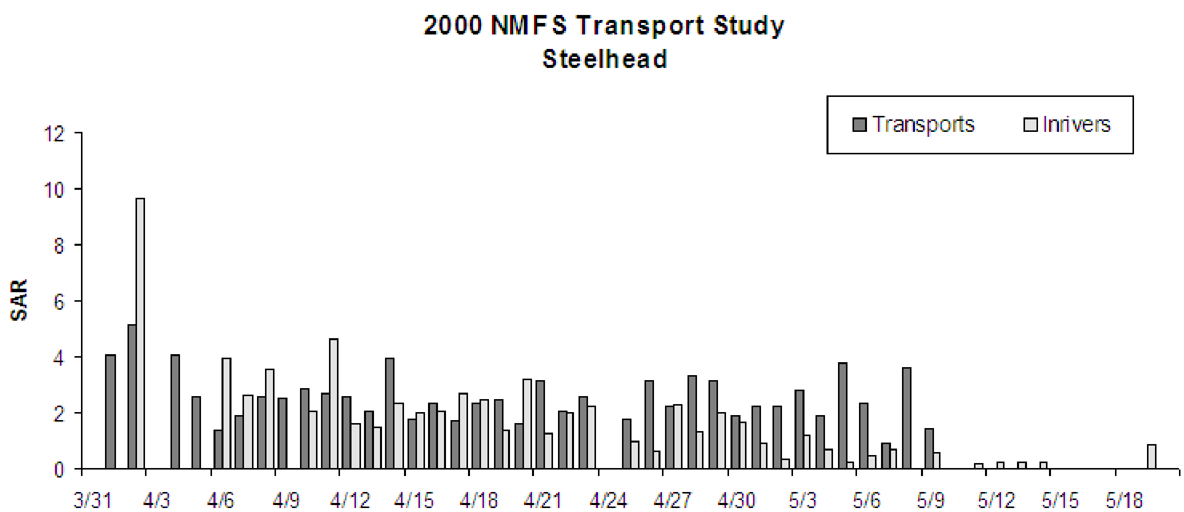

Figure 10. SARs for transported and inriver migrant steelhead smolts tagged at Lower Granite Dam in 2000. Data presented as 3-day running averages of daily releases and juvenile releases.

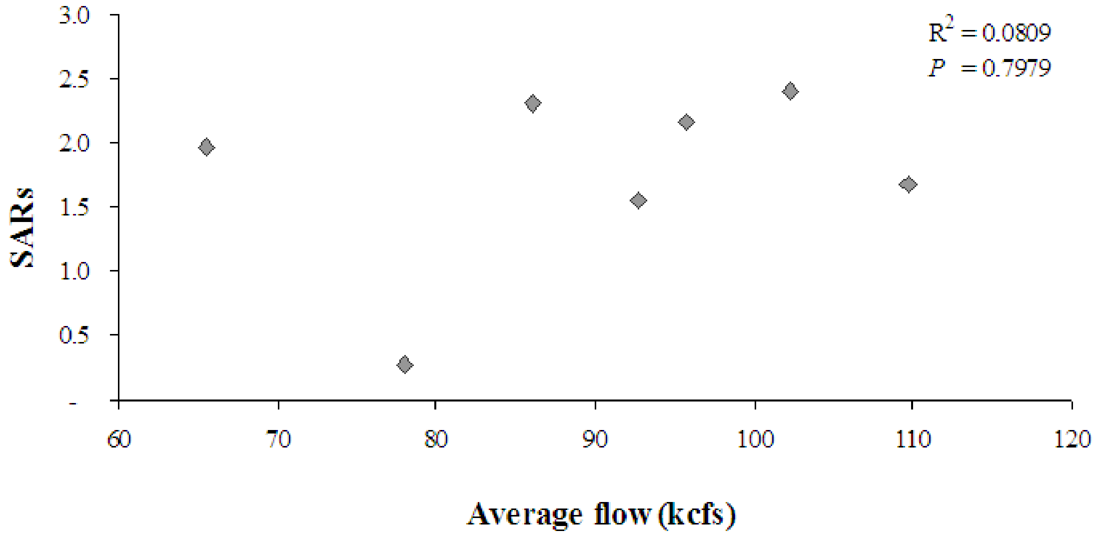

Figure 11. Steelhead inriver SARs vs. Snake River flow measured at Lower Monumental Dam in spring 2000.

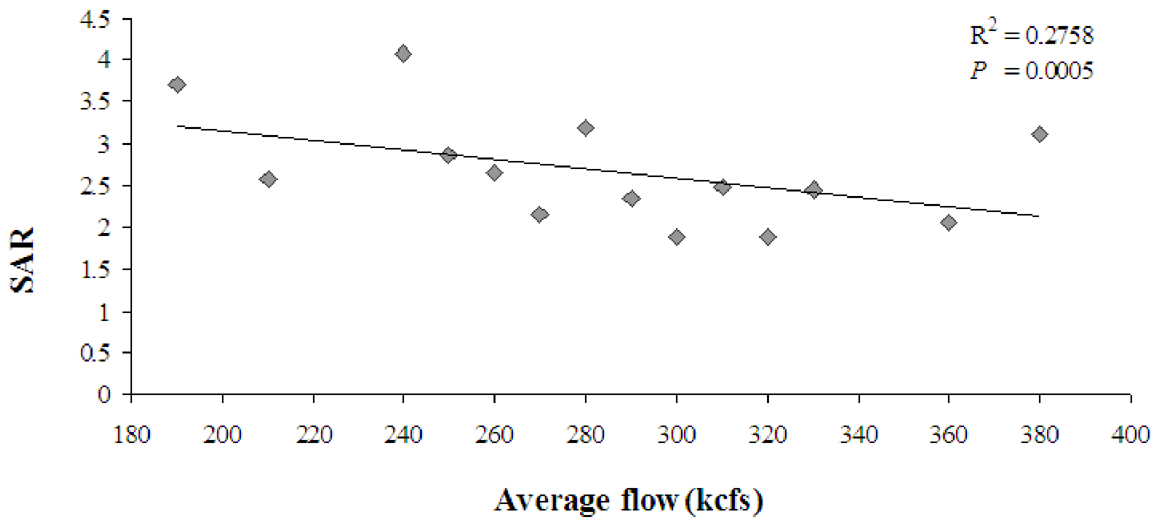

Figure 12. Steelhead transport SARs vs. Columbia River flow measured at Bonneville Dam in spring 2000.

Discussion

We observed relatively high SARs for some transported groups; SARs ranged between 2.5 and 3.5% for transported fish tagged after about 5 May 1999, suggesting that marking does not affect adult return rates significantly. Likewise, the SARs for transported wild steelhead smolts tagged in 2000 consistently ranged between 2.0 and 4.0% for much of the juvenile migration, with some age-1- and all age-2- and age-3-ocean adults yet to be recovered. These SARs are comparable to those of fish PIT-tagged in hatcheries and traps upstream from the dam.

Post-tagging delayed mortalities were virtually absent during tagging in 2001, in contrast to the relatively high mortality levels seen in most studies conducted during the 1970s (Williams and Matthews 1995).

For most transport studies conducted on both spring/summer chinook salmon and steelhead smolts since 1995, annual T/Is, while indicating a transport benefit, were lower than expected when compared to concurrent estimates of inriver survival (Marsh et al. 2000, 2001; Muir et al. 2001). The exception to date is for wild steelhead smolts tagged at Lower Granite Dam and transported from Little Goose Dam in spring 2000. The annual T/I for these fish is approaching the expected value and continues to increase as additional adults are recovered.

Contemporary study designs and the use of PIT tags allow for a more refined analysis of SARs and T/Is than the simple calculation of an annual average used in earlier transportation evaluations. An example is the ability to calculate statistics for groups of fish by the period when they were marked, which has revealed an interesting trend in the T/I data: SARs are much higher for transported smolts tagged late rather than early in the migration season.

The drop in SARs for smolts transported early in the season has resulted in lower-than-expected T/Is, although T/Is tend to increase rather abruptly and remain relatively stable through the remainder of each season. However, the timing of these abrupt increases in transport SARs has been inconsistent among study years, with the increases occurring progressively earlier in the season.

In 1995, the increase did not occur until about 5 May (Marsh et al. 2000), while in 1998 and 1999 the increases occurred about 1 and 2 weeks earlier, respectively. During both these years, transportation benefits were equivocal early in the season and roughly at expected levels later in the season. However, average T/Is over the entire season were lower than expected for 1998 and 1999.

To the best of our knowledge, these temporal changes in the SAR for transported fish are not related to any environmental or biological factor examined during the freshwater phase. Apparently, a rather significant post-release phenomenon affected the survival of transported fish during most of April but then dissipated over a short period. The SARs of inriver migrants PIT tagged and released in April may not have been affected in most cases because the great majority of these fish would not have arrived below Bonneville Dam until after the SARs for transported fish had increased substantially.

We do not know if this pattern for transported fish will occur in future years, but it did occur in four out of the five recent studies with sufficient adult returns to detect seasonal changes. The exception was a study on wild steelhead in 2000.

We are unaware of any temporal differences in migrational behavior, physiology, disease, or transport methodologies that might explain the abrupt and sustained increases in SARs of transported fish. The pattern is more likely related to arrival timing of smolts in the estuary and near-ocean environments in recent years.

Conditions that might vary annually in these areas include predator abundance and dynamics (birds, fish, and marine mammals), alternative prey availability for those predators (anchovies, herring, and sand lance), and abundance of prey for juvenile salmon (enhanced survival of fast-growing, robust smolts). Changes in predator/prey dynamics coincidental with the 1976/1977 oceanic regime shift (Hare et al. 1999), particularly during early ocean residence (Hargreaves 1997), likely played a major role in low annual SARs and in high variation in SARs within and between years.

If the SAR pattern observed for transported fish from 1995 through 1999 continues, it will have important implications for management. Transport of smolts early in the juvenile migration may provide little to no benefit, but deciding when to begin transporting smolts in any given year may be problematic because of annual variability in the timing of the increase in transport SARs. Some evidence, however, suggests that the 1995 through 1999 results are probably atypical over longer time frames.

For example, if survival were invariably poor or disadvantageous for early-migrating smolts, it is unlikely that early migration would now be a common attribute of the wild salmon populations, as has been recently documented (Achord et al. 1997). Surely, natural selection pressures would have seriously impeded, if not altogether prevented, the development of this life history characteristic. In SAR data from the most recent study on wild steelhead, the trend of lower survival for early transported fish is absent. It will be important and instructive to determine if this is the beginning of an altogether different survival dynamic or is simply a short-term anomaly.

SNAKE RIVER FALL CHINOOK SALMON

Methods

As with spring/summer chinook salmon and steelhead, we did not release inriver migrant groups of fall chinook salmon because of extremely low Snake River flows expected low survival rates for fish migrating in the river. We marked Snake River fall chinook (subyearling) salmon only for transportation index releases. Methods used to calculate sample sizes for these index groups were the same as those described for wild yearling chinook salmon and steelhead: with α at 0.05, and w at 0.002 (0.2%), and with an expected transport SAR of 0.01 (1.0%), then N (the number of fish required for the transport group at Lower Granite Dam) is10,000.

Because we released tagged Lyons Ferry Hatchery subyearling chinook salmon upstream from Lower Granite Dam, we had to increase N to ensure sufficient numbers would be recaptured and diverted for transport at Lower Granite Dam. We assumed a 25-30% rate of survival to Lower Granite Dam and a 50% collection efficiency at the dam (both reasonable estimates based on previous PIT-tag detections and expected poor survival conditions); therefore, we needed approximately 7.4 times more fish released (roughly 75,000) to obtain the required number of fish for statistical accuracy from a transportation index group ($10,000 \times (1.0/(0.27 \times 0.5)) \approx 75,000$).

Juveniles were dipped from hatchery raceways, anesthetized, and PIT-tagged. After receiving the tag, study fish were sent to containers on transport trucks to recover. When all tagging was complete for each day, the trucks were driven to the release site above Lower Granite Dam (rkm 254). Prior to release, river water was pumped into the containers for acclimation of the fish to the new water. After acclimation, fish were released into the main Snake River. Mortalities were removed from the containers prior to release. The total time from tagging to release was less than 12 hours, so post marking delayed mortality estimates were only for this short period.

Using the separation-by-code PIT-tag diversion systems at each of the collector dams, all subyearling fall chinook salmon marked at Lyons Ferry State Hatchery and released above Lower Granite Dam were transported from the dam at which they were collected. Our primary transport group was formed of fish transported from Lower Granite Dam.

We will utilize detections of PIT-tagged Snake River fall chinook salmon adults obtained at Bonneville, McNary, and Lower Granite Dams in each of the five years following tagging as juveniles. A 95% CI will be calculated for the transport index SAR when adult returns are complete.

Results

From 18 through 25 May 2001, we PIT tagged a total of 74,413 hatchery subyearling fall chinook salmon at Lyons Ferry State Hatchery, releasing 74,245 into the Snake River upstream from Lower Granite Dam at River Kilometer 254. The number of fish tagged daily ranged from 5,293 to 11,629 (Appendix Table 2). Mean fork length of these fish was 84.4 mm, and delayed mortality (12-hour) was 0.2%.

Through 1 November 2001, 22,559 fish were collected at Lower Granite Dam, 18,907 of which were diverted to the transportation group using the dam's separation-by-code PIT-tag diversion system.

COLUMBIA RIVER FALL CHINOOK SALMON

Methods

In summer 2001, we PIT tagged subyearling chinook salmon from the population collected at McNary Dam. As in other transport studies, sample size requirements for a study comparing transport SARs to inriver SARs were calculated by determining precision around the estimated T/I such that one-half the width of the confidence interval for the true T/I does not contain the value 1, or the confidence interval for the true natural-log transformed T/I, Ln(T/I), does not contain 0. Therefore, for a desired α and β and specified true T/I, the number of fish needed was determined as

$$\mathrm{Ln}(T/I) - (t_{\alpha/2} + t_{\beta}) \times \mathrm{SE}(\mathrm{Ln}(T/I)) \approx 0 \quad \text{and}$$

$$\mathrm{SE}(\mathrm{Ln}(T/I)) \approx \mathrm{SQRT}(1/n_T + 1/n_I) = \mathrm{SQRT}(2/n),$$

where $n_T = n_I = n$ equals the number of adult returns per treatment (n for transported and inriver groups set equal for simplicity).

From the previous two statements, the sample size required for sufficient adult returns for comparison was expressed as

$$n \approx 2 \times (t_{\alpha/2} + t_{\beta})^2 / [\mathrm{Ln}(T/I)]^2.$$

We set α = 0.05 and β = 0.20, and used an expected SAR for transported fish of at least 1.0% for each species. Sample sizes needed at McNary Dam are listed as follows (N denotes the number of juveniles):

T/I	n	NT	N_I (= $N_T \times$ T/I)	N_{Total}
1.3	228	22,800	29,640	52,440

Therefore, the study required a total of 52,440 subyearling fall chinook salmon tagged at McNary Dam in 2001.

We attempted to sample the population collected at McNary Dam at levels that would permit marking a constant rate of fish during the juvenile migration. The percentage of the daily collection we handled depended upon the number of fish collected. Once established, we attempted to hold the proportion sampled constant throughout the season. Any deviations were recorded. This will provide a total adult-return estimate for marked/transported fish that represents the number of fish collected and transported. Marked study fish were held an average of 12 hours before release into a barge or the McNary Dam tailrace.

All handling and tagging was done using preanesthesia techniques (Matthews et al. 1997). After the fish were anesthetized, they were gravity-transferred in water into the sorting building. Fish for marking were sorted from the collected population and sent to one of several marking stations to receive a PIT tag.

There are no collector dams below McNary Dam; therefore, all fish transiting juvenile bypass systems are returned to the river regardless of whether they have a PIT tag or not. Detections of bypassed fish were recorded at John Day and Bonneville Dams.

We will recover adults in each of the five years following the tagging of subyearling chinook salmon. The procedures for data analysis were described by Marsh et al. (1996).

To calculate 95% CIs for various T/Is, we will pool release days until a minimum of two adults are contained in both transport and in-river categories. Empirical variance estimates will be calculated using these temporal replicates. Daily (or multiple-day pooled) facility collection numbers will be used to weight the replicates to provide weighted seasonal T/Is applicable to the untagged population. The weighted mean T/Is and CIs will then be constructed on the natural logarithm scale (i.e., such ratio data were assumed to be log-normally distributed) and back-transformed.

Results

From 19 June through 27 July 2001, we PIT tagged a total of 62,012 subyearling fall chinook salmon collected at McNary Dam (Appendix Table 3). Of this total, 23,250 were transported and released below Bonneville Dam, while 38,546 were released into the McNary Dam tailrace to migrate inriver. Post-marking delayed mortality (24-hour) averaged 0.3% for the period.

A summary of the numbers of subyearling chinook salmon PIT tagged at McNary Dam in 2001 is shown below:

	Number	Mean fork length (mm)
Transported fish	23,250	106.2
Inriver migrants	38,546	104.4

INCIDENCE OF MARINE MAMMAL ABRASIONS AT LOWER GRANITE DAM

We continued to monitor the prevalence of marine mammal tooth and claw abrasions on adult spring/summer chinook salmon at Lower Granite Dam during 2000. Prevalence averaged 20.9% on adults examined, with 39.0% of the abrasions consisting of open wounds of varying severity (Table 5). As in the past, abrasion prevalence was generally higher during the early portion of the adult run (Achord et al. 1992; Matthews et al. 1992; Harmon et al. 1993, 1995, 1996, 2000; Marsh et al. 1996, 1997, 1998, 2000). With the levels of abrasions observed, it is likely that marine mammals continue to negatively affect depressed runs of Snake River spring/summer chinook salmon.

Table 5. Weekly prevalence (4 April to 12 July) of marine mammal abrasions on adult spring/summer chinook salmon at Lower Granite Dam in 2001.

Date	Sample size	Incidence (%)
4-8 April	31	22.6
9-15 April	15	13.3
16-22 April	57	24.6
23-29 April	154	27.3
30 April-6 May	70	34.3
7-13 May	64	23.4
14-20 May	38	28.9
21-27 May	42	9.5
28 May-3 June	53	18.9
4-10 June	60	11.7
11-17 June	43	7.0
18-24 June	35	8.6
25 June-1 July	19	10.5
2-8 July	13	15.4
9-12 July	4	0.0
	Total 698	Average 20.9*

* Open wounds were associated with 39.0% of the abrasions.

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APPENDIX

Data Tables

Appendix Table 1. Total wild spring/summer chinook salmon and wild steelhead tagged at Lower Granite Dam in spring 2001.

	Tagged		Barged	
Tag date	Chinook	Steelhead	Chinook	Steelhead
10-Apr	14	73	14	73
11-Apr	68	100	68	100
12-Apr	77	88	77	88
13-Apr	43	73	43	73
16-Apr	38	82	38	82
17-Apr	75	107	75	107
18-Apr	30	84	30	84
19-Apr	115	117	115	117
20-Apr	67	80	67	80
21-Apr	68	137	68	137
22-Apr	114	152	114	152
23-Apr	83	142	83	142
24-Apr	80	163	80	163
25-Apr	145	184	145	184
26-Apr	223	580	223	580
27-Apr	506	402	506	402
28-Apr	562	637	562	637
29-Apr	1,108	478	1,108	478
30-Apr	1,004	1,208	1,004	1,208
1-May	448	874	448	874
2-May	498	1,833	497	1,833
3-May	477	1,450	477	1,450
4-May	436	658	430	657
5-May	1,003	747	1,001	747
6-May	830	612	830	612
7-May	464	296	464	296
8-May	276	138	276	138
9-May	795	281	795	281

Appendix Table 1. Continued.

	Tagged		Barged	
Tag date	Chinook	Steelhead	Chinook	Steelhead
10-May	945	199	945	199
11-May	905	204	905	204
12-May	467	139	467	139
14-May	349	114	349	114
15-May	958	156	958	156
17-May	899	593	899	593
18-May	636	607	636	607
19-May	488	488	488	488
21-May	218	307	218	307
22-May	268	576	268	576
23-May	354	262	354	262
24-May	133	113	133	113
25-May	209	87	209	87
29-May	75	64	75	64
30-May	57	50	57	50
31-May	49	35	49	35
1-Jun	61	39	61	39
4-Jun	56	8	56	8
5-Jun	128	2	128	2
6-Jun	203	11	203	11
7-Jun	573	59	573	59
8-Jun	32	95	32	95

Appendix Table 2. Total hatchery subyearling chinook salmon tagged at Lyons Ferry Hatchery in spring 2001.

Tag date	Tagged	Released
18-May	5,305	5,296
19-May	8,395	8,388
20-May	8,643	8,626
21-May	10,606	10,590
22-May	11,652	11,638
24-May	11,370	11,343
25-May	11,575	11,540
26-May	6,867	6,866

Appendix Table 3. Total subyearling chinook salmon tagged at McNary Dam in summer 2001.

	Released	
Tag date	Inriver	Barge
19-Jun	4,285	—
21-Jun	1,804	1,200
25-Jun	2,485	1,817
27-Jun	2,629	1,919
29-Jun	2,397	1,664
3-Jul	2,434	1,826
5-Jul	1,380	1,055
9-Jul	1,925	1,409
11-Jul	2,508	1,854
13-Jul	2,502	1,807
17-Jul	2,961	1,897
19-Jul	2,742	1,615
23-Jul	2,790	1,653
25-Jul	3,144	1,836
27-Jul	2,560	1,698
Totals	38,546	23,250