Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2002

Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
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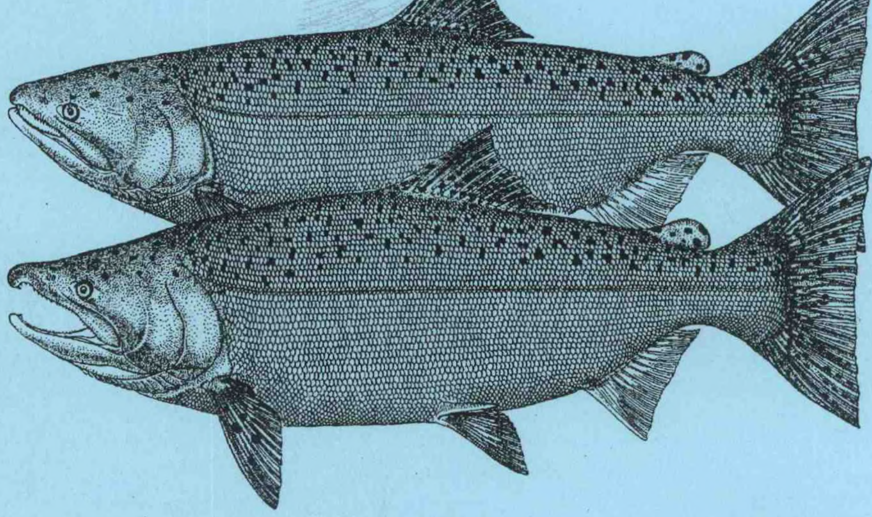
February 2004



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Report of research by

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Northwest Fisheries Science Center
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EXECUTIVE SUMMARY

Since 1995, the National Marine Fisheries Service has PIT-tagged Snake River yearling chinook salmon and steelhead smolts arriving at Lower Granite Dam to evaluate the U.S. Army Corps of Engineers' smolt transportation program. In 2000 we revised the study protocol to better reflect the experience of wild composite populations migrating in the river. In 2001, we began transportation evaluations of Snake River hatchery subyearling (fall) chinook tagged at Lyons Ferry Hatchery and Columbia River wild and hatchery subyearling chinook salmon tagged at McNary Dam. In 2002, evaluations began for Columbia River hatchery yearling chinook salmon. Here we report results from 2002 studies on each of these populations.

Snake River Yearling Chinook Salmon and Steelhead (1999-2002)

From 9 April through 12 June 2002, we PIT-tagged a total of 39,538 wild yearling chinook smolts, transporting 4,970 by barge to a release site below Bonneville Dam, and releasing 34,059 into the tailrace of Lower Granite Dam to migrate in the river. From March to August 2002, we recovered 114 wild age-2-ocean transported fish and 149 wild age-2-ocean inriver migrant fish from smolts tagged at Lower Granite Dam in 2000. Based on all preliminary returns to date (jacks recovered in 2001 and age-2-ocean fish in 2002), the ratio of adult transported to inriver migrant fish (T/I) was 1.2 for fish marked as smolts in 2000. We also detected 20 jacks at Lower Granite Dam from the 2001 tagging season, wherein all study fish were transported.

From 9 April through 12 June 2002, we PIT-tagged 48,780 wild steelhead smolts at Lower Granite Dam, with 4,899 transported by barge and 43,506 released into the tailrace. In July 2002, we began recovering age-3-ocean steelhead adults from smolts tagged in 1999. Through 30 June 2003, we detected five age-3-ocean adults at Lower Granite Dam: two were transported fish, and were included in the study; three were inriver fish that had been detected as juveniles, and these were removed from the study. To date we have recovered a total of 530 (444 hatchery and 86 wild) transported steelhead and 89 (81 hatchery and 8 wild) inriver steelhead from the 1999 smolt marking. The T/I was 1.5 for all fish combined (jacks and 1-, 2-, and 3-ocean adults), with 1.4 for hatchery fish and 2.6 for wild fish.

In 2002 we also began detecting age-2-ocean steelhead adults from smolts tagged in 2000. Through 30 June 2003, we have detected a total of 428 transported fish and 152 inriver fish, and the T/I for smolts tagged in 2000 is 2.2. Through 30 June 2003, we also recovered 200 wild age-1-ocean steelhead transported from Lower Granite Dam in 2001 (all steelhead smolts were transported in 2001).

Snake River Subyearling Chinook (2001-2002)

From 29 May through 14 June 2002, we PIT tagged a total of 98,332 subyearling chinook salmon at Lyons Ferry State Hatchery, releasing 97,916 of these fish into the Snake River above Lower Granite Dam at River Kilometer (Rkm) 254. Through 15 December, 12,344 of these fish were subsequently collected and transported from Lower Granite Dam and released below Bonneville Dam. Because subyearling salmon continue to migrate through the spring following hatching, the number of inriver migrants not detected at a Snake River dam can be determined only after spring 2003. Post-marking delayed mortality (24-hour) was 0.2% for the period. Of inriver-migrant fish detected at downstream collector dams (7,128 fish though 15 December), 71.2% (5,075) were transported using separation-by-code PIT-tag diversion systems (slide gates). Beginning in August 2002, we also recovered subyearling chinook jacks from smolts PIT tagged in 2001: we recovered 17 transported hatchery fish and 25 hatchery inriver migrant fish.

Columbia River Hatchery Yearling Chinook (2002)

We began transportation evaluations of upper Columbia River hatchery yearling chinook salmon from McNary Dam in 2002. In mid-January, the U.S. Fish and Wildlife Service and Biomark, Inc. began PIT-tagging a total of 349,485 yearling chinook salmon at Winthrop (19,988), Entiat (59,960), and Leavenworth Fish Hatcheries (269,537). Using a new PIT-tag diversion system installed for this study in the juvenile collection facility at McNary Dam, 50,381 fish were diverted to raceways for transportation, while 17,100 were returned to the river for estimates of inriver survival past Bonneville Dam.

Columbia River Subyearling Chinook at McNary Dam (2001-2002)

From 19 June through 15 August 2002, we PIT-tagged hatchery and wild subyearling chinook salmon collected at McNary Dam. Of the 94,967 fish tagged, 38,320 were transported and released below Bonneville Dam, while 56,310 were released into the McNary Dam tailrace. Post-marking delayed mortality (24-hour) averaged 0.3% for the period. Beginning in August 2002, we also recovered subyearling chinook salmon jacks from smolts PIT tagged at McNary Dam in 2001. We recovered 12 transported fish and 19 inriver-migrant fish.

CONTENTS

SNAKE RIVER YEARLING CHINOOK SALMON AND STEELHEAD (1999-2002)

Introduction

In 1995, 1996, 1998, and 1999, we PIT-tagged yearling chinook salmon and steelhead smolts at Lower Granite Dam to compare adult returns between inriver-migrant smolts and smolts transported and released below Bonneville Dam.[1] To accommodate these comparisons, the slide gates at downstream collector dams were set to return inriver-migrating smolts to the river to continue their migration.

However, based on adult returns (and from fish PIT-tagged in the same years upstream from Lower Granite Dam) we found lower smolt-to-adult return rates (SARs) for inriver migrants that had been detected in the juvenile bypass system (JBS) at Snake River collector dams and higher SARs for inriver migrants that had been bypassed only at Lower Granite Dam. Further, fish that were never detected in the JBS of a Snake River dam also had higher SARs than fish that had been detected on the Snake River.

Thus, we revised the transportation study design in 2000 to compare the SARs of transported fish only to inriver migrants with no detection history on the Snake River other than initial collection and tagging at Lower Granite Dam. In addition, the study was modified to use only wild fish, since these are the populations of concern. These modifications will ensure that the yearling chinook salmon and steelhead selected for transportation evaluations at Lower Granite Dam will be representative of their respective composite populations.

As in previous years, evaluations for this release year will be based on the ratio of SARs between transported and inriver-migrant fish (T/I ratios). For each species, 95% confidence intervals (CIs) will be calculated around the T/I, and T/Is will be regressed against inriver variables and compared to concurrent inriver survival estimates.

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1 Comparison were not made in 1997 because there were too few smolts available in the river to provide sufficient adult returns for evaluation.

Methods

Sampling and Tagging of Juveniles

With winter precipitation returning to more normal levels in 2002, we resumed the collection and tagging protocol established in 2000 for Snake River wild yearling chinook salmon and wild steelhead[2] (Marsh et al. 2001). However, instead of releasing all tagged fish into the Lower Granite Dam tailrace, and thereby forming transport groups only from fish collected at Little Goose Dam, we added a transport group from Lower Granite Dam.

To create transport study groups from Little Goose and Lower Monumental Dams, we set the separation-by-code PIT-tag diversion systems at both dams to divert 80% of the fish collected in the JBS. We then estimated the number of study fish arriving in the tailrace of each dam that had not been previously detected using the methods of Sandford and Smith (2002)(see Appendix B for an overview of this method). This estimate established the base number of inriver-migrating study fish needed.

Fish collected at Little Goose and Lower Monumental Dams that were not diverted to transportation (20% of those collected at the dam) were returned to the river. At the dams below Lower Monumental Dam, we diverted all PIT-tagged study fish collected in the juvenile fish facilities back to the river. Detections of fish at these dams were used in survival estimates, which followed the methods of Iwamoto et al. (1994).

Juvenile Sample Sizes

We estimated juvenile sample sizes needed for transport and inriver groups to discern a true T/I of at least 1.4 (a 40% difference) based on transport SARs relative to estimated inriver SARs. We also required precision around the estimated T/I such that one-half the width of a confidence interval (approximately two standard errors) of the true T/I will not contain the value 1, or the confidence interval of the ln-transformed true T/I would not contain 0.

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2 In 2001, comparisons could not be made because all fish collected at Lower Granite Dam were transported due to low river flows with poor anticipated survival for inriver migrant fish.

We proceeded by testing the null hypothesis, that there is no difference between the SARs of transported and inriver migrant fish. For a given type I error rate ($t_{\alpha/2}$, rejection of a true null hypotheis) and type II error rate (t_β, acceptance of a false null hypothesis), the number of fish needed for tagging was determined as

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

and

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

where n is the number of adult returns per treatment (for either n_T transport or n_I inriver groups). Equation 2 was calculated using a delta method approximation (Mood et al. 1974) and the formula for the variance of a ratio of two binomial proportions (Burnham et al. 1987; which was also derived using a delta method approximation). The previous two statements imply that the sample 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 difference of 40% (T/I = 1.4), and we expect a transport SAR of at least 2.1% for each species, the sample sizes needed at Lower Granite Dam were:

$$n = 142$$
$$N_T = 6{,}800$$
$$N_I = 9{,}520$$
$$\text{Total juveniles} = 16{,}320$$

Where N_T is the number of juveniles needed for the transport cohort and N_I is the number of fish needed for the inriver cohort (6,800 × 1.4).

In 1995, the first year that yearling chinook salmon smolts were PIT-tagged and released into the Lower Granite Dam tailrace for transportation evaluations, 29.7% were never again detected. Because numbers of non-detected fish in subsequent years have been similar, we chose 20% as a conservative estimate of the proportion of inriver migrants that would not be detected on the Snake River below Lower Granite Dam.

Based on this estimate, the inriver cohort must sustain an 80% loss (from inriver fish that were detected and thus excluded from the cohort) and still be large enough to discern a T/I of 1.4 or more. This required the release of approximately 47,600 fish (9,520/0.2) into the Lower Granite Dam tailrace.

Similarly, based on data from previous study years, we conservatively estimated that 15% of inriver migrant steelhead smolts would not be detected on the Snake River after tagging and release into the tailrace of Lower Granite Dam. Consequently, we needed to PIT-tag and release 63,500 (9,520/0.15) wild steelhead smolts into the Lower Granite Dam tailrace to obtain sufficient numbers for analysis.

Similar methods were used to estimate the numbers of smolts needed for transport cohorts from Little Goose and Lower Monumental Dams. For example, assuming an approximate 40% collection efficiency at Little Goose Dam, and to ensure statistical resolution of a minimum T/I of 1.4, we needed 19,400 (47,600 × 0.4) wild yearling chinook salmon smolts and 25,400 (63,500 × 0.4) wild steelhead smolts to be collected for transport at that dam. By the same methods, we needed 6,800 fish of each species for transport directly from Lower Granite Dam.

In studies conducted since 1995, we have sampled a relatively constant proportion of the yearling chinook and steelhead populations arriving at Lower Granite Dam throughout the juvenile migration season. This has resulted in fewer fish being tagged early and late in the spring migration season and more being tagged in mid-season. However, because data collected recently have shown dramatic within-season differences in SARs and T/Is (Marsh et al. 2000, Zabel and Williams 2002), we adjusted our tagging schedule to mark more fish in the early and late segments of the juvenile migration season.

To accomplish this, we attempted to tag equal numbers of fish in 5-day periods rather than in proportion to the number of fish collected. To calculate the overall SARs and T/Is, we will weight returns from the 5-day blocks of tagged fish proportional to the daily collection numbers. This will allow greater resolution of any differences in SARs and T/Is over the entire migration season.

Other than these changes, the basic collection and handling followed the methodology described by Marsh et al. (1996, 2001). Marked inriver fish were held an average of 24 hours before release into the Lower Granite Dam tailrace, and all releases were made in the early morning. We continued using the recirculating anesthetic water system described by Marsh et al. (2001).

Exclusion Criteria for 2002 Study Fish

Marsh et al. (1996) provides complete details on how inriver study fish were tracked as they passed through the collection systems at dams downstream from Lower Granite Dam during this study. During 2002, there were several factors that affected inclusion criteria for transportation study fish at the dams, and these are described below.

Little Goose and Lower Monumental Dams--At Little Goose and Lower Monumental Dams, fish detected on coils leading to the transportation holding raceways were assumed to have been transported, while fish detected on diversion system coils were assumed to have been returned to the river.

However, at the end of the smolt migration, we were informed by USACE project biologists that there were periods when all fish in the transportation holding raceways were released to the river at both Little Goose and Lower Monumental Dams. Therefore, we removed from the transportation data set the records of all fish whose final detections were on coils leading to transportation holding raceways during these release periods. All fish detected at Little Goose and Lower Monumental Dams that were not part of the transport data set were removed from the inriver data set.

McNary Dam--Prior to 11 July 2002, McNary Dam was in bypass mode, and all tagged and untagged fish collected (except tagged fish from the Columbia River hatchery study described below) were returned to the river after passing through PIT-tag detectors and were included as inriver-migrant study fish. After this date, all fish were transported and therefore excluded from the study.

Because there was a chance that some wild yearling chinook and wild steelhead PIT-tagged at Lower Granite Dam were inadvertently diverted to transportation raceways along with the Columbia River hatchery study fish, we examined the passage records of all our study fish. Fish that were not observed returning to the river at McNary Dam were removed from the inriver study group.

Adult Recoveries and Data Analysis

In 2002, the procedures for data analysis described by Marsh et al. (1996) were modified using the methods of Sandford and Smith (2002). The inriver study group included only fish that had never been detected as smolts on the Snake River below Lower Granite Dam.

To calculate 95% CIs for various 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 to be log-normally distributed) and back-transformed.

Results

Sampling and Tagging of Juveniles

We PIT-tagged study fish at Lower Granite Dam from 9 April through 12 June 2002. During this period, we tagged 39,561 wild yearling chinook salmon (Table 1 and Appendix Table A1), and the number of fish tagged daily ranged from 35 to 1,762. Of the 39,561 wild yearling chinook salmon tagged, 34,059 were released into the tailrace and 4,970 were transported in barges from Lower Granite Dam. Through 15 December, 9,649 and 5,399 tagged fish (first detection below Lower Granite Dam) were collected and transported from Little Goose and Lower Monumental Dams, respectively.

We also tagged 48,874 wild steelhead smolts (Table 1 and Appendix Table A1). The number of fish tagged daily ranged from 167 to 2,714. Of the 48,874 wild steelhead tagged, 43,506 were released into the tailrace and 4,899 were transported in barges from Lower Granite Dam. Through 15 December, 12,499 and 7,019 tagged fish (first detection below Lower Granite Dam) were collected and transported from Little Goose and Lower Monumental Dams, respectively.

Based on mortality counts from the inriver-holding tanks, post-marking delayed mortality (24-hour) averaged 0.7% for yearling chinook salmon and 0.2% for steelhead over the entire tagging season. This value is exceptionally low, considering that we tagged virtually every fish sampled. Only a few fish that were either severely injured or

Table 1. Numbers and mean fork lengths of wild yearling chinook salmon and wild steelhead smolts PIT-tagged and released at Lower Granite Dam, 2002.

	Yearling chinook salmon		Steelhead	
	Number	Mean fork length (mm)	Number	Mean fork length (mm)
		Inriver		
tagged	34,553	106.7	43,874	175.3
released	34,059	106.7	43,506	175.3
		Transport		
tagged	5,008	107.8	4,917	176.1
released	4,970	107.8	4,899	176.1

exhibited gross symptoms of bacterial kidney disease were rejected for tagging. By tracking the unique PIT-tag code of each mortality, we determined the body condition recorded when the fish was still alive during tagging.

As in past years (Marsh et al. 1996, 1997, 2000), descaling appeared to impact post-marking delayed mortality for yearling chinook salmon. When tagged, 0.7% of all fish were recorded as descaled; however, of the delayed mortalities, 4.3% were fish that had been recorded as descaled during tagging. For steelhead, descaling and body injury seemed to have similar impacts on post-tagging delayed mortality. Of all steelhead tagged, 1.3% were descaled and 4.7% had a body injury; respective mortality rates from these groups were 3.5 and 11.8%.

We recorded fork lengths of all fish during tagging, and we encountered yearling chinook salmon that were obviously of hatchery origin but had partial or no fin clips. In 1996, we had 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) indicated that a maximum fork length of 123 mm included almost all wild non-clipped fish. After a reevaluation, we accepted 124 mm as the maximum fork length assigned to wild yearling chinook salmon (from the entire population of unclipped fish).

Detection of Inriver Migrant Juveniles

As inriver study fish continued their seaward migration after tagging and release, some were detected at Snake River dams downstream from Lower Granite Dam. Of the 34,059 wild yearling (spring/summer) chinook salmon tagged and released into the Lower Granite Dam tailrace as inriver migrants, 13,717 (40.3%) were never detected on the Snake River after tagging. Of the 20,342 (59.7%) detected fish, 9,649 were transported from Little Goose Dam, 6,366 were transported from Lower Monumental Dam (5,399 of the 6,366 were detected for the first time after tagging at Lower Granite Dam), and 4,327 were detected and returned to the river at one or more Snake River dam.

Of the 43,506 wild steelhead released into the Lower Granite Dam tailrace 17,655 (40.6%) were not detected at a downstream Snake River dam. Of the remaining 25,851 (59.4%) fish that were detected, 12,499 were transported from Little Goose Dam, 8,198 were transported from Lower Monumental Dam (7,019 were detected for the first time after tagging at Lower Granite Dam), and 5,154 were bypassed at one or more of the Snake River dams.

At both Little Goose and Lower Monumental Dams, our initial goal was to transport 80% of the yearling chinook salmon and steelhead collected. However, from the collection at Little Goose Dam, 75.7% of the yearling chinook and 77.2% of the steelhead were transported. From the collection at Lower Monumental Dam, 73.9% of the yearling chinook and 75.2% of the steelhead were transported.

Based upon PIT-tag-detections at John Day and Bonneville Dams and in the paired-trawl net in the estuary, we made preliminary estimates of survival from the Lower Granite Dam tailrace to the McNary and Bonneville Dam tailraces. For wild yearling chinook salmon smolts, we estimated survivals of 70.7 and 39.2% over the two respective reaches; for wild steelhead, we estimated survivals of 56.8 and 19.5% over the respective reaches.

Adult Recoveries and Data Analysis

Yearling Chinook Salmon–Final results on yearling chinook salmon marked in 1999 were reported in Marsh et al. (2003).

At Lower Granite Dam, we recovered age-2-ocean yearling chinook salmon tagged as smolts at Lower Granite Dam in 2000 (Table 2). The first adult was observed at the dam on 26 April and the last on 29 July.

As with the age-1-ocean steelhead returns last year (Marsh et al. 2003), SARs for wild yearling chinook salmon smolts transported in 2000 exhibited a different seasonal dynamic than was observed for each previous study year (Fig. 1). Transport SARs from fish tagged in 2000 were higher (ranging between 1.0 and 4.0% in most cases) for fish transported during the first half of the outmigration. Unlike in previous studies when the highest transport SARs were recorded for fish tagged later in the outmigrations, SARs were higher for fish tagged earlier in the outmigration in 2000. The SARs for inriver study fish were also higher for fish tagged early in the 2000 outmigration. Similar to transported fish, only a few inriver fish returned from smolts tagged after 11 May.

Table 2. Recoveries through 14 October 2002 of wild adult yearling chinook salmon marked at Lower Granite Dam in 2000 and 2001 transportation evaluations. The 2000 inriver group includes only fish never detected at a Snake River dam after release into the Lower Granite Dam tailrace. No PIT-tags were recovered above Lower Granite Dam for either release year.

		Adult returns at Lower Granite Dam	
Group	Number released[a]	Number	%
2000			
Transport	17371	122	0.7
Inriver	26340	157	0.6
2001[b]			
Transport	17,597	20	0.11

a Numbers adjusted as described in Sandford and Smith (2002).

b Because of extreme low flows in 2001, all tagged fish were transported.

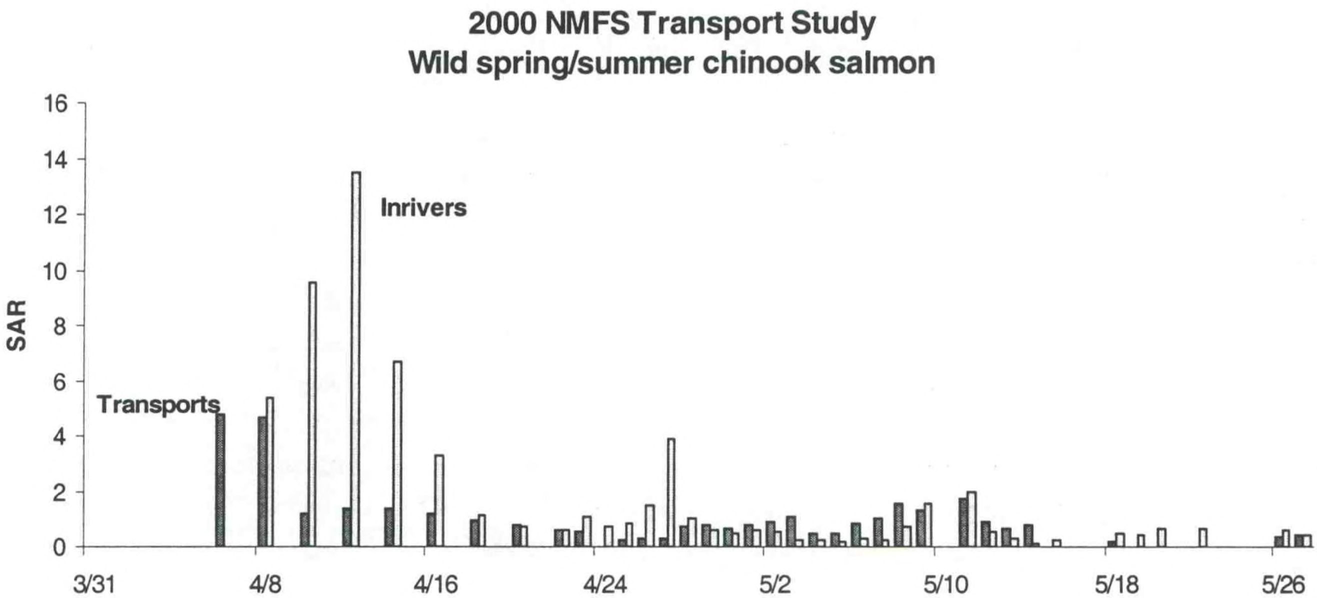

Figure 1. Smolt-to-adult return ratios (SARs) for transported and inriver migrant yearling chinook salmon smolts tagged at Lower Granite Dam in 2000. Data presented as 3-day running averages of daily releases.

Of the 381 total adults that returned to Lower Granite Dam from the 2000 marking, 357 (jacks and age-2-ocean adults combined) were observed at Bonneville Dam, and all 344 age-2-ocean adults were observed at McNary Dam (detection at McNary Dam began in 2002). For age-2-ocean adults, average travel times from Bonneville Dam to Lower Granite Dam were 14.7 and 15.1 days for inriver and transported fish, respectively. For jacks, average travel times from Bonneville Dam to Lower Granite Dam were 10.5 days for both groups of fish. The percentage of adults detected at Bonneville Dam that were subsequently detected at Lower Granite Dam (conversion rate) for age-2-ocean adults was 80.9% for transported fish and 84.1% for inriver fish. Overall conversion rates (jacks and age-2-ocean adults combined) were 81.4% for transported fish and 84.2% for inriver fish.

In 2002, we also recovered jack yearling chinook salmon tagged as smolts at Lower Granite Dam in 2001 (Table 2). The first jack was observed at the dam on 11 May and the last on 15 July.

During their return, 22 jacks were observed on detection coils at Bonneville Dam. Of these 22 fish, 21 successfully migrated from Bonneville to Lower Granite Dam, a conversion rate of 95.5%.

Steelhead–During spring 2003 we completed recoveries of age-3-ocean steelhead tagged as smolts in 1999 (Table 3). Hatchery and wild fish accounted for 84.2 and 15.8% 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 hatchery fish were not adipose-fin clipped. The respective T/Is for hatchery and wild fish were 1.4 (95% CI 1.2, 1.7) and 2.6 (95% CI 1.6, 5.6) 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 observed for yearling chinook salmon tagged in the same year (Fig. 2). Initial transport SARs were low, increased sharply during the third week of April, and remained high through mid-May. Inriver SARs were also initially low, increased the third week of April, but then decreased after early May.

For all adult steelhead returns from the 1999 marking, 138 transported adults (115 hatchery and 23 wild) and 28 inriver adults (25 hatchery and 3 wild) were detected in the Adult Fish Facility at Bonneville Dam. Of these adults, 124 transport adults

Table 3. Recoveries through 30 June 2003 of adult steelhead marked as smolts at Lower Granite Dam in 1999, 2000, and 2001 for transportation study evaluations. The inriver groups include only fish not detected as juveniles 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	%
	1999		
Transport			
Hatchery	41,109	444	1.08
Wild	6,062	86	1.42
Total	47,171	529	1.12
Inriver[b]			
Hatchery	10,442	81	0.78
Wild	1,471	8	0.54
Total	11,913	89	0.75
	2000		
Transports	24,735	985	3.98
Inrivers[b]	23,516	433	1.84
	2001[c]		
Transports	15,978[b]	200	1.25

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 (2002).

c Because of extreme low flows in 2001, all tagged fish were transported.

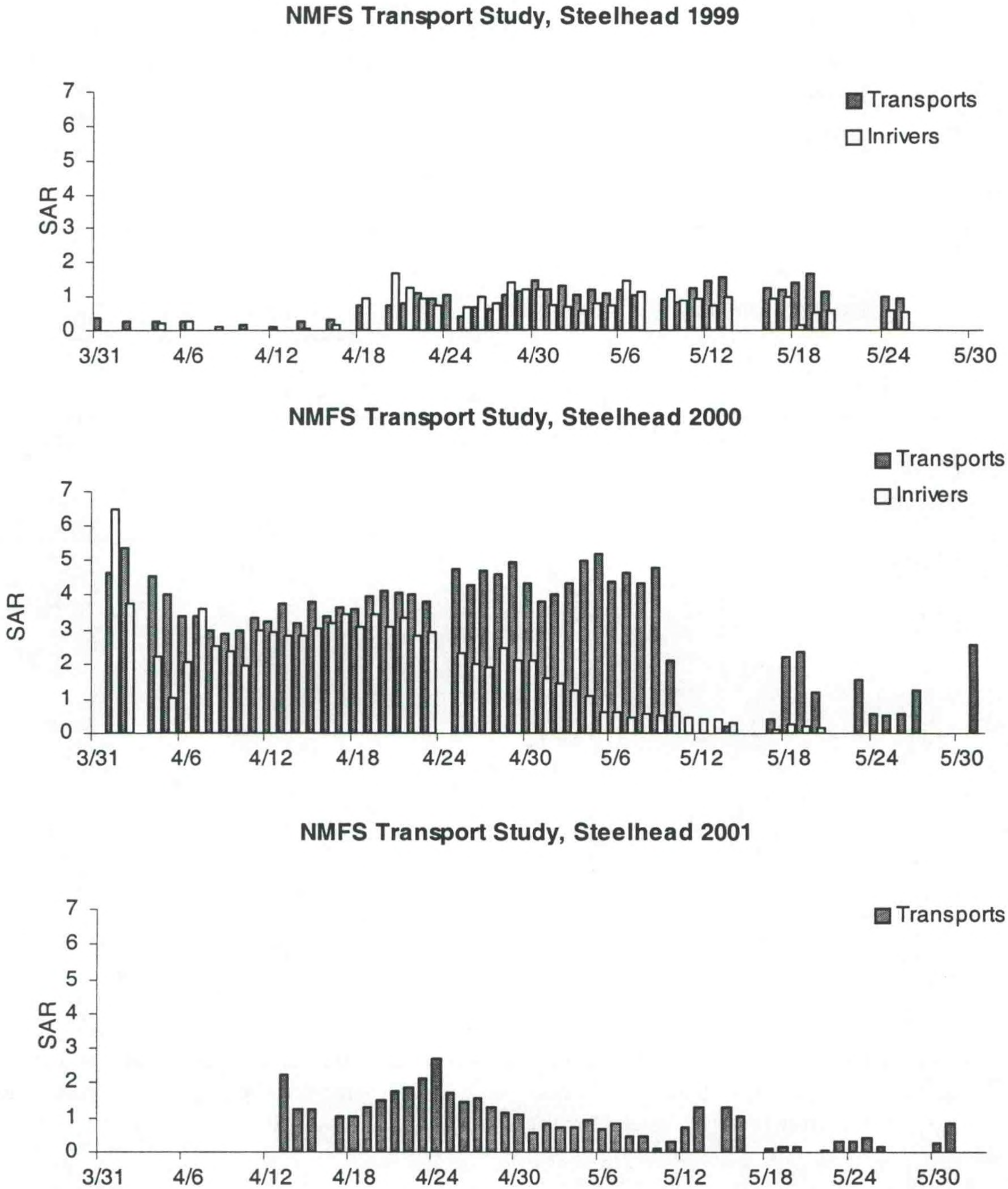

Figure 2. Smolt-to-adult return ratios (SARs) as of spring 2002 for transported and inriver migrant steelhead smolts tagged at Lower Granite Dam, 1999-2000. No inriver migrants were tagged in 2001. Data are presented as 3-day running averages of daily juvenile releases.

(104 hatchery and 20 wild) and 22 inriver adults (21 hatchery and 1 wild) were detected passing Lower Granite Dam. Conversion rates for transported hatchery and wild steelhead were 90.4% and 87.0%, respectively. The percentage of inriver migrant adults detected at Bonneville Dam and subsequently detected at Lower Granite Dam (conversion rate) was 84% for hatchery steelhead and 33.3% for wild steelhead.

Initial returns of transported age-2-ocean wild steelhead tagged as smolts in 2000 were about double those of their non-transported cohorts (Table 3). For the 2000 smolt migration, the study design for steelhead also differed from previous years: we PIT-tagged only wild fish, and all fish were released into the Lower Granite Dam tailrace. The transport group was formed only from fish collected at and transported from Little Goose Dam. The inriver group was formed from fish that were not detected at a Snake River collector dam below Lower Granite Dam. All other fish (fish that were collected at Little Goose Dam and returned to the river, and fish that were collected at Lower Monumental Dam, whether transported or not) were removed from the evaluation.

For the first time since 1995, when we began PIT-tagging fish for transportation studies, the wild steelhead smolts transported in 2000 only had high SARs during the first half of the migration (Fig. 2). In previous years, we generally observed the highest transport SARs after the first week in May. Inriver SARs were also higher than previous years (although, generally less than transport SARs), but began decreasing earlier than transport SARs.

Through spring 2003, we recovered 200 age-1-ocean steelhead tagged as smolts in 2001 (Table 3). The initial SARs for wild steelhead smolts transported in 2001 exhibit a similar temporal trend as was observed for the 2000 study year (Fig. 2).

Discussion

The inriver and transport SARs for both species began to increase in the late 1990s and for some hatcheries have reached levels reported by Raymond (1988) during the late 1960s, early 1970s, and mid-1980s. These higher return rates have provided larger numbers of returning adults, which allows for smaller confidence intervals about the SAR estimates and opportunities to examine other potentially important trends in the data. It is of utmost importance that we continue to gather as much data as possible on the relationship between salmon populations and the Federal Columbia River Hydropower System during this period of high post-Bonneville-Dam survival.

For most transport studies conducted on both yearling chinook salmon and steelhead smolts since 1995, annual T/Is, while indicating a transport benefit, have been lower than expected based on 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, based on concurrent survival estimates, and continues to increase as additional adults are recovered.

Contemporary study designs and the use of PIT tags allow for more refined analyses of SARs and T/Is than the simple calculation of an annual average used in previous transportation studies. Calculating the statistics for groups of fish by the period when they were marked as smolts revealed an interesting time trend in the data. Most recent annual T/Is (1995-1999) have been lower than expected, primarily because transport SARs were much lower for smolts tagged earlier than later in the juvenile migration season.

The timing of the rather abrupt increases in transport SARs has been inconsistent among study years, moving progressively earlier in the seasons in more recent years. 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. Transport benefits during these years were equivocal early in the season and at roughly expected levels later in the season. As a result, when averaged over all juvenile migration seasons, the overall T/Is were lower than expected for all years.

The within-year dichotomies in the results of these studies were peculiar and unexpected. To the best of our knowledge, the rather abrupt within-year increases in transport SARs were not related to any environmental or biological factor that has been examined during the freshwater phase of the juvenile migration. For fish tagged through 1999, apparently, a rather significant, post-release phenomenon affected the survival of transported fish during most of April and then dissipated over a rather short period. The SARs of inriver migrant cohorts of these fish may not have been affected because the great majority of these fish would not have arrived below Bonneville Dam until after the phenomenon had dissipated. In contrast, initial results from 2000 and 2001 have shown a reverse trend--fish transported early in the season have higher SARs than those transported later.

There are at least two possible explanations for this observed temporal difference. First, the process responsible for the sharp increases in transport SARs noticed in the 1995, 1998, and 1999 study years is now occurring in March or early April. A second possible explanation is that, although the April SARs of transported fish in 2000 and 2001 are higher than any of the previous three study years, they still would have represented the lowest point of the season. However, instead of the process that caused the transport SARs to soar the previous three years, an exact opposite process occurred, causing the SARs to plummet to nearly zero.

We are unaware of any temporal differences in migrational behavior, physiology, disease, or transport methodologies that might explain the abrupt and sustained seasonal changes 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 play a major role in low annual SARs and high within- and between-year variation in SARs.

First noticed with steelhead marked in 2000, but now also seen with chinook marked in 2000 and steelhead marked in 2001, it appears that there may have been another dramatic shift in the annual SAR dynamics of study fish. Returns from 2000 chinook and steelhead, and early returns from 2001 steelhead, indicate that fish marked in April survived well, but fish marked after 9 May did not.

We have three years of data (1995, 1998, and 1999) indicating that transport early in the year may not be beneficial or is neutral, but transport later in the year provides the expected benefit. However, the most recent two years of data indicate the exact opposite, that transportation early in the season was beneficial but transportation after early May was not (although no inriver migrants have returned from the later marking either). We are working with our estuary and near-ocean researchers to determine what processes may be driving the changes we have observed in seasonal SARs. When we understand these processes, we may understand how to use transportation to most fully benefit spring-migrating salmon populations.

SNAKE RIVER SUBYEARLING CHINOOK SALMON (2001-2002)

Introduction

Transportation of subyearling chinook salmon was repeatedly evaluated at McNary Dam on the Columbia River from the late 1970s through the late 1980s. However, due to logistical constraints, similar evaluations have never been conducted on Snake River stocks even though these stocks are transported to mitigate for losses during downstream passage through the hydropower system.

Fisheries agencies and tribes have strongly indicated their desire to have the study conducted under a summer spill program. However, whether or not spill offers the best inriver-migration condition for Snake River subyearling chinook salmon migrating in summer is unknown. The Bonneville Power Administration has indicated that summer spill in the Snake River will require an adjustment to their transmission system hardware and that such an adjustment can not be completed until summer 2004. Therefore, we conducted the study in 2002 under extant inriver conditions. Testing transportation under a summer spill program is scheduled to begin in 2007. Results over the next five years will provide information needed to refine the study design and a baseline under current conditions from which to compare later results from a summer spill scenario.

Methods

Sampling and Tagging of Juveniles

We used supplemental fish from Lyons Ferry Hatchery to evaluate the efficacy of transporting subyearling chinook salmon from Lower Granite Dam. In 2001, roughly 1,500,000 hatchery subyearlings were released above Lower Granite Dam, and releases of this size or larger are expected to continue. In 2002, we PIT-tagged a fraction of these fish at the hatchery and trucked them to the release site on the Snake River (RKm 254), approximately 30 km upstream from the confluence of the Clearwater and Snake Rivers. They were acclimated and released for eventual recapture and sorting into transport and inriver-migrating groups at Lower Granite Dam (Rkm 173).

The method used to calculate juvenile sample sizes needed for the 2002 transportation study of subyearling chinook salmon was similar to that described previously for wild yearling chinook salmon and steelhead (Equations 1-3).

Error rates were $\alpha = 0.05$ and $\beta = 0.20$, and the minimum expected transport SAR was 1.0%. The samples needed to be large enough to detect a minimum real T/I of 2.0 (a difference between SARs of 100% or more); therefore, the number of juveniles needed for tagging was

$$\begin{aligned} n &= 34 \\ N_T &= 3{,}400 \\ N_I &= 6{,}800 \\ \text{Total} &= 10{,}200 \end{aligned}$$

Where n is the target number of adult returns, N_T is the number of juveniles needed for the transport cohort, and N_I is the number needed for the inriver cohort (3,400 × 2.0).

The release of tagged Lyons Ferry Hatchery subyearling chinook salmon above Lower Granite Dam required increasing the number of fish tagged over that shown above to provide sufficient numbers for each group at Lower Granite Dam. We assumed 60% survival to Lower Granite Dam and 50% fish guidance efficiency (FGE) based on previous PIT-tag detections. Thus, we calculated that we needed 22,712 inriver fish released above the dam (1.0/0.6 × 0.5).

Based upon previous PIT-tag detections, we estimated that 15-30% of the subyearling chinook salmon arriving at Lower Granite Dam (and not detected passing through the dam) would never be detected at a downstream dam on the Snake River. Therefore, to provide an adequate number of undetected inriver-migrants below Lower Granite Dam required tagging and release of roughly 150,000 (22,712/0.15) fish above the dam. This also provided transport test fish to be collected at Lower Granite Dam in numbers that well exceeded study design requirements.

At Lyons Ferry Hatchery, fish were hand-dipped from raceways, anesthetized, and PIT-tagged. After receiving the tag, study fish were routed to containers on transport trucks to recover. When all tagging was complete for each day, the trucks were driven to the release site. 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 Snake River. Mortalities were removed from the containers prior to release. The total time from tagging to release was less than 12 hours, so delayed mortality estimates were only for a 12-hour period.

The separation-by-code PIT-tag diversion systems at each collector dam were set to divert 80% of the subyearling chinook salmon for transport from the dam at which they were collected. The remaining 20% were released back to the river to estimate inriver survival to below John Day Dam. Our primary transport group was formed of fish transported from Lower Granite Dam.

Adult Recoveries and Data Analysis

We will recover Snake River subyearling chinook salmon adults in each of the five years following tagging as juveniles. Adults will be detected in the fish ladders of Bonneville, McNary, and Lower Granite Dams, with Lower Granite Dam the primary recovery site. A 95% CI will be calculated for the transport index SAR when adult returns are complete.

Results

Sampling and Tagging of Juveniles

From 29 May through 14 June 2002, we PIT-tagged a total of 98,332 hatchery subyearling chinook salmon at Lyons Ferry State Hatchery, releasing 97,916 into the Snake River. The number of fish tagged daily ranged from 4,723 to 12,703 (Table 4 and Appendix Table A2). Delayed mortality (12-hour) was 0.4%.

Through 15 December 2002, of the 97,916 hatchery subyearling chinook salmon released into the Snake River, 21,128 (21.6%) were detected at least once at a downstream collector dam. Final dispositions of the 97,916 fish released were as follows: 12,344 transported from Lower Granite Dam; 3,222 transported from Little Goose Dam (2,550 of these were detected for the first time at Little Goose Dam); 1,853 transported from Lower Monumental Dam (1,370 were detected for the first time at Lower Monumental Dam); 76,788 never detected at a Snake River collector dam; and 3,709 bypassed at one or more of the Snake River collector dams.

Adult Recoveries and Data Analysis

At Lower Granite Dam in 2002, we recovered subyearling chinook salmon jacks tagged as smolts at Lyons Ferry Hatchery in 2001 (Table 5). The first jack was observed on 8 September and the last on 31 October. Because of the low flows experienced in 2001, we marked only enough fish to collect a transport index group at Lower Granite

Table 4. Numbers and mean fork length of Snake River hatchery subyearling chinook salmon PIT-tagged at Lyons Ferry Hatchery and released above Lower Granite Dam, 2002.

	Snake River hatchery subyearling chinook salmon	
	Number	Mean fork length (mm)
Released	97,916	68.5

Table 5. Recoveries through 14 October 2002 of Snake River hatchery subyearling chinook salmon PIT-tagged at Lyons Ferry Hatchery and released above Lower Granite Dam for transportation evaluations in 2001 and recovered as jacks in 2002.

		Adult returns at Lower Granite Dam	
Group	Number released[a]	Number	%
Transports	18,902	17	0.09

[a] Numbers adjusted as described in Sandford and Smith (2002).

Dam. We report here the adult returns from all fish marked for the transport index group, including those not collected at Lower Granite Dam. Adult fish that were not transported as juveniles in 2001 and that were not detected at a downstream Snake River dam are referred to as inriver migrants, even though no inriver cohort was released in that year.

We recovered 71 jacks during 2002. Of the 71 fish, 21 were removed from analysis because they were detected as juveniles at a Snake River dam downstream from Lower Granite Dam. Of the remaining jacks, 19 were transports and 31 were inrivers. SARs to Lower Granite Dam were 0.10% for the group transported from Lower Granite Dam and 0.12% for inriver fish. A 95% CI will be calculated when adult returns are complete.

During their return, 63 jacks (21 transports, 24 inrivers, and 18 removed fish) were observed on detection coils in the Bonneville Dam ladders. Through 14 October 2002, of these 63 fish, 42 (10 transports, 16 inrivers, and 16 removed fish) have successfully migrated from Bonneville to Lower Granite Dam. The Zone 6[3] fishery on subyearling chinook harvest probably had little impact on jacks, but may impact adult returns in the coming years.

Discussion

In 2002, Lyons Ferry Hatchery fish suffered an outbreak of bacterial gill disease which stunted fish development, and the hatchery fish designated for marking were in poor condition. We sorted through all of the fish on more than one occasion to obtain fish large enough and in good enough condition to tag. Instead of marking the 150,000 fish needed for the study, we were only able to tag 98,332 because of the poor condition of these fish. One indication of the condition of the fish we marked is the fact that, while we tagged roughly one-third more fish in 2002 (98,332) than in 2001 (74,413), we collected and transported one-third less fish in 2002 (12,250) than in 2001 (18,907). This may seriously impact the precision of our T/I estimate for these fish.

3 Zone 6 defined as the Columbia River from Bonneville Dam to McNary Dam.

COLUMBIA RIVER HATCHERY YEARLING CHINOOK SALMON (2002)

Introduction

Even though several multi-species transportation studies were conducted from McNary Dam from the late 1970s through the late 1980s, these studies were conducted under conditions that no longer exist. A new juvenile collection facility was constructed and began operating at McNary Dam in 1994. Therefore, we initiated new studies to test the efficacy of smolt transportation from McNary Dam.

Methods

Sampling and Tagging of Juveniles

To provide a holistic approach to evaluations of SARs and T/Is for fish originating only in the Columbia River upstream from McNary Dam, we PIT-tagged and released yearling chinook salmon that originated in hatcheries in this area. Transport and inriver-migrating groups were not established until the fish passed McNary Dam. The number of fish transported was a known value, while the number of fish arriving in the dam's tailrace was estimated (Sandford and Smith 2002).

The method used to calculate sample sizes for a transport study at McNary Dam was the same as described above for wild yearling chinook salmon and steelhead at Lower Granite Dam. Setting $\alpha = 0.05$, $\beta = 0.20$ and an expected transport SAR of at least 1.0%, sample sizes needed to detect a 1.2 T/I (20% difference) at Bonneville or McNary Dam are listed below:

$$n = 473$$
$$N_T = 47{,}300$$
$$N_I = 56{,}760$$
$$\text{Total} = 104{,}060$$

Where n is the target number of adult returns, N_T is the number of juveniles needed for the transport cohort, N_I is the number needed for the inriver cohort (47,300 × 2.0).

The above numbers were required at McNary Dam. Because we released fish from hatcheries upstream from the dam, larger numbers of fish were required to provide sufficient numbers to be collected for transport at the dam. Since survival from the hatcheries to the dam and collection efficiencies at the dam differ among the different populations of fish, the numbers required for tagging at the hatcheries also differed. To account for these differences, we examined the estimated survival to the dam and detection probabilities for the three populations of hatchery fish released previously in the Columbia River above the dam.

We calculated survival to the dam and the probability of detection in the collection system at the dam for PIT-tagged fish released from Leavenworth Hatchery in spring 2000. These fish migrated through the McNary Dam project primarily in May and were almost completely past the dam by early June. During that period, spill at the dam averaged a relatively constant 40% of the total river flow. Estimated survival was 0.586 (s.e. 0.015) and the detection probability for fish arriving at the dam was 0.229 (s.e. 0.015). Therefore, we needed to release roughly 355,000 (47,300/0.586/0.229) PIT-tagged fish from the hatchery to realize the number of study fish required in the yearling chinook salmon transport group at McNary Dam.

We intended to tag fish at several hatcheries upstream from McNary Dam in numbers roughly proportional to each hatchery's contribution to the total number of fish released. Numbers of fish proposed for tagging at each hatchery were

Population	Hatchery	Number tagged
Yearling chinook salmon	Leavenworth	240,000
	Entiat	60,000
	Methow	35,000
	Winthrop	20,000
	Total	355,000

Adult Recoveries and Data Analysis

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

To calculate 95% CIs for various T/Is, release days will be pooled 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

Fish marking was conducted by the U.S. Fish and Wildlife Service and Biomark, Inc. during winter and early spring 2002. No fish were marked at Methow Hatchery so an additional 30,000 fish were marked at Leavenworth Hatchery (Table 6).

Through 15 December 2002, out of the 349,485 marked and released fish, we collected 67,903 at McNary Dam. Of these fish, 50,803 were transported and the remaining 17,100 fish were bypassed back to the river.

Based upon PIT-tag detections at John Day and Bonneville Dams and in the pair-trawl detection system in the estuary, we made preliminary estimates of survival from the hatchery to the McNary Dam and Bonneville Dam tailraces. For fish from Winthrop, Entiat, and Leavenworth Hatcheries, we estimated survivals to McNary Dam tailrace of 50.6, 53.8, and 57.6% respectively. We regrouped all fish arriving at McNary Dam and used this group to estimate survival from McNary Dam to the tailrace of Bonneville Dam (83.0%). Based on this estimate, survival from hatchery release to the Bonneville Dam tailrace was 42.0, 44.7, and 47.8% for Winthrop, Entiat and Leavenworth Hatcheries respectively.

Table 6. Numbers and mean fork length of Mid-Columbia River hatchery yearling spring chinook salmon PIT-tagged at various hatcheries, 2002.

Hatchery	Number tagged	Number released	Number of fish transported at McNary Dam
Winthrop	19,988	19,987	2560
Entiat	59,960	59,955	8,824
Leavenworth	269,537	269,013	38,997

COLUMBIA RIVER SUBYEARLING CHINOOK SALMON AT MCNARY DAM (2001-2002)

Introduction

Adult return rates for smolts PIT-tagged in the Snake River in 1994 and transported from McNary Dam were lower than for smolts transported from other dams. Even though the numbers and percentages of returning adults were low for all groups in 1994, they were considerably lower for fish transported from McNary Dam, in spite of the fact that a new bypass and collection facility began operating that year.

In 2002, we continued with the second year of a study investigating transportation of subyearling chinook salmon from McNary Dam using our revised study protocol. The purpose of this study was to gather data on the efficacy of transporting these fish under contemporary conditions.

Methods

Sampling and Tagging of Juveniles

In summer 2002, we PIT-tagged subyearling chinook salmon from the population collected at McNary Dam. As in other transport studies, sample size calculations for a transport study comparing transport SARs to inriver SARs were based on determining precision around the estimated T/I such that the one-half width of a confidence interval on the true T/I would not contain the value 1, or the confidence interval on the true ln-transformed T/I would not contain 0.

Numbers of juvenile fish needed were determined using methods similar to those described for yearling chinook salmon and steelhead at Lower Granite Dam (Equations 1-3). For $\alpha = 0.05$, $\beta = 0.20$, and an expected transport SAR of at least 1.0% for each species, the sample sizes needed to detect a T/I of 1.3 (at least a 30% difference) were:

$$n = 228$$
$$N_T = 22{,}800$$
$$N_I = 29{,}640$$
$$\text{Total} = 52{,}440$$

Where n is the target number of adult returns, N_T is the number of juveniles needed for the transport cohort, N_I is the number needed for the inriver cohort (22,800 × 1.3).

We attempted to sample the population collected at McNary Dam at levels that would permit marking a constant proportion of fish throughout the outmigration. Thus, the percentage of the daily collection we handled depended upon the total number of fish collected each day. Once established, we attempted to hold the proportion sampled constant throughout the season, and any deviations were recorded. This provided a total adult-return estimate for marked/transported fish that represented 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 marking was done using the preanesthesia techniques of Matthews et al. (1997). After fish were anesthetized, they were gravity-transferred in water to the sorting building. Fish designated for marking were sorted and sent to one of several marking stations to receive a PIT tag.

Because of the every-other-day transport schedule and the higher water temperatures often encountered at McNary Dam, we decided to mark the transport and inriver groups on separate days. This allowed us to tag and release larger groups and to spread the tagging out over the week and the season.

There are no dams with collection facilitites for transportation below McNary Dam; therefore, all fish bypassed downstream from McNary Dam were returned to the river regardless of whether they had been PIT-tagged. Detections of bypassed fish were recorded at John Day and Bonneville Dams.

Adult Recoveries and Data Analysis

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

To calculate 95% CIs for various T/Is, release days will be pooled until a minimum of two adults are contained in both transport and inriver 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

Sampling and Tagging of Juveniles

From 20 June through 15 August 2002, we PIT-tagged a total of 94,967 subyearling chinook salmon collected at McNary Dam (Table 7 and Appendix Table A3). Of this total, 38,320 were transported and released below Bonneville Dam, while 56,310 were released into the McNary Dam tailrace to migrate inriver. Post-marking delayed mortality (24-hour) averaged 0.5% for the period. Based on PIT-tag-detections at John Day and Bonneville Dams and on detections by the pair-trawl system in the estuary, we made a preliminary estimate of 53.7% survival from the McNary Dam tailrace to the Bonneville Dam tailrace.

Adult Recoveries and Data Analysis

At McNary Dam in 2002, we recovered subyearling chinook salmon jacks tagged as smolts at the dam in 2001 (Table 8). The first jack was observed on 10 September and the last on 29 October. We recovered 33 jacks during 2002. Of the 33 fish, 13 were transports and 20 were inrivers. Preliminary SARs to McNary Dam were 0.03% for the group transported from the dam and 0.04% for inriver fish. A 95% CI will be calculated when adult returns are complete. During their return, 27 jacks (8 transports and 19 inrivers) were observed on detection coils in the Bonneville Dam ladders. Of these 27 fish, 23 jacks (7 transports and 16 inrivers) successfully migrated from Bonneville to McNary Dam.

Table 7. Numbers and mean fork length of subyearling chinook smolts PIT-tagged at McNary Dam, 2002.

	Number tagged	Number released	Mean fork length (mm)
Transports	38,382	38,320	101.3
Inrivers	56,585	56,310	101.6

Table 8. Recoveries through 15 December 2002 of subyearling chinook jacks marked as smolts at McNary Dam in 2001 for the transportation study.

		Jack returns at McNary Dam	
Group	Number released	Number	Preliminary SAR (%)
Transports	23,254	13	0.03
Inrivers	38,551	20	0.04

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APPENDIX A

Data Tables

Appendix Table A1. Total wild spring/summer chinook salmon and wild steelhead tagged at Lower Granite Dam in spring 2002.

	Transport released		Inriver tagged		Inriver released		Inriver post-tagging mortality		Inriver lost tags	
Tag date	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead
4/9	35	40	222	289	219	287	1	1	1	1
4/10	67	31	421	218	416	216	1	1	0	0
4/11	123	72	835	651	825	648	1	0	0	1
4/12	122	48	887	448	853	447	5	0	0	0
4/15	148	78	1,009	753	1,003	749	2	3	0	1
4/16	203	99	1,347	882	1,334	864	23	3	5	0
4/17	58	87	387	799	381	796	3	1	0	2
4/18	198	233	1,193	1,902	1,188	1,891	4	3	0	7
4/19	148	134	951	1,062	947	1,055	5	1	0	5
4/22	59	59	382	520	376	517	3	0	0	3
4/23	71	73	453	729	452	727	1	1	0	1
4/24	156	115	981	878	974	870	6	3	1	4
4/25	129	54	755	431	754	428	0	0	0	1
4/26	252	55	1,510	458	1,507	456	3	0	0	0
4/29	66	42	382	354	381	352	1	2	0	0
4/30	37	52	255	406	252	401	3	3	0	2
5/1	60	30	380	290	368	282	12	7	0	1
5/2	77	44	552	442	548	440	3	0	0	2
5/3	99	47	573	467	572	464	0	1	0	2
5/6	73	24	433	247	431	245	2	1	0	1
5/7	32	39	337	563	304	561	25	2	0	0
5/8	90	64	943	951	907	950	18	1	0	0
5/9	53	34	745	625	738	622	4	3	0	0
5/10	42	42	499	672	488	666	6	0	0	1
5/13	52	49	611	884	606	883	1	1	0	0

Appendix Table A1. Continued.

Tag date	Transport released		Inriver tagged		Inriver released		Inriver post-tagging mortality		Inriver lost tags	
	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead
5/14	46	25	499	467	498	465	1	0	0	1
5/15	43	34	562	633	559	630	1	1	0	2
5/16	28	28	397	636	391	632	6	3	0	0
5/17	42	38	622	873	593	846	24	25	0	2
5/18	27	39	778	764	769	762	2	1	0	1
5/19	43	62	1,063	1,282	1,050	1,278	12	0	0	0
5/20	129	222	802	1,677	798	1,669	2	4	1	2
5/21	218	89	1,308	687	1,301	685	5	0	0	2
5/22	192	198	1,069	1,508	997	1,506	7	0	0	1
5/23	136	186	809	1,507	749	1,507	3	0	0	0
5/24	153	324	926	2,390	921	2,374	3	1	0	5
5/25	176	210	1,070	1,504	1,065	1,498	3	1	0	0
5/26	125	220	724	1,642	721	1,631	3	2	0	2
5/28	124	128	708	983	698	979	7	1	0	3
5/29	99	138	621	1,070	617	1,069	2	0	0	1
5/30	156	238	909	1,821	898	1,816	8	1	0	2
5/31	122	275	676	2,130	667	2,123	4	3	0	1
6/1	135	247	905	1,901	897	1,892	4	1	0	4
6/2	157	155	902	1,259	898	1,256	3	2	0	1
6/3	149	127	886	976	879	976	3	0	0	0
6/4	70	67	410	501	405	498	0	0	0	0
6/5	66	60	378	516	378	513	0	0	0	1
6/6	49	33	275	420	275	280	0	0	0	0
6/7	31	32	180	242	180	241	0	1	0	0
6/10	4	35	31	231	31	230	0	1	0	0
6/11	0	20	0	147	0	147	0	0	0	0
6/12	0	24	0	186	0	186	0	0	0	0

Appendix Table A2. Total hatchery subyearling chinook salmon tagged at Lyons Ferry Hatchery in spring 2002.

Tag date	Tagged	Released
5/29	4,785	4,723
5/30	5,933	5,885
5/31	5,510	5,464
6/3	6,733	6,698
6/4	5,168	5,141
6/5	7,251	7,201
6/6	10,115	10,062
6/7	8,933	8,933
6/10	9,041	9,023
6/11	7,246	7,239
6/12	8,731	8,706
6/13	12,727	12,703
6/14	6,159	6,138

Appendix Table A3. Total subyearling chinook salmon released at McNary Dam in summer 2002.

	Release	
Tag date	Inriver	Transport
6/20/2002	2,382	---
6/24/2002	1,774	---
6/25/2002	---	2,866
6/26/2002	3,207	---
6/27/2002	---	2,555
7/1/2002	---	2,489
7/2/2002	2,261	---
7/3/2002	---	2,575
7/4/2002	3,528	---
7/8/2002	2,127	---
7/9/2002	---	2,051
7/10/2002	3,703	---
7/11/2002	---	2,776
7/15/2002	---	2,645
7/16/2002	3,457	---
7/17/2002	---	1,625
7/18/2002	2,543	---
7/22/2002	3,710	---
7/23/2002	3,275	---
7/24/2002	2,749	---
7/25/2002	---	2,735
7/29/2002	---	3,282
7/30/2002	4,651	---
7/31/2002	---	1,903
8/1/2002	2,444	---
8/5/2002	2,884	---
8/6/2002	---	2,073
8/7/2002	4,259	---
8/8/2002	---	3,408
8/12/2002	---	2,906
8/13/2002	3,742	---
8/14/2002	---	2,431
8/15/2002	3,664	---

APPENDIX B

Overview of Statistical Methodology

For each day of the migration season, we estimated numbers of fish passing each dam, developing a series of daily passage estimates. These daily estimates were used to estimate SARs according to the method of Sandford and Smith (2002). A brief synopsis of this method follows (shown here for Little Goose Dam).

1) Fish detected on day k at Lower Monumental Dam that had previously been detected at Little Goose Dam were grouped according to day of detection (passage) at Little Goose Dam.

2) Fish detected on day k at Lower Monumental Dam that had *not* previously been detected at Little Goose Dam were assigned a day of detection at Little Goose Dam based on the distribution at Little Goose Dam of fish detected at both dams. This step assumed that the passage distribution for non-detected fish at Little Goose Dam was proportionate to that of their cohorts detected at Little Goose Dam.

3) This process was repeated for each day of detection at Lower Monumental Dam during the juvenile migration season.

4) All fish detected at Lower Monumental Dam were assigned a passage day i at Little Goose Dam whether or not they had been detected at Little Goose Dam.

5) Probability (p) of detection at Little Goose Dam on day i was estimated by comparing the proportion of fish detected on day i to the total number of fish known to have arrived at the dam on day i. Numbers were adjusted for fish that had been transported from Little Goose Dam.

6) The total number of fish arriving at Little Goose Dam on day i (LGO_i) was estimated by dividing the total number detected at Little Goose Dam on day i (including bypassed and transported fish) by the estimated probability of detection on day i.

We then estimated SARs for various detection-history categories, in particular for fish transported from a dam, for fish bypassed back to the river at one or more dams, and for fish never detected at a Snake River dam. To do this, we developed daily passage estimates at Little Goose Dam using the following process:

7) For each group that passed Little Goose Dam on day *i* (LGO_i; see step 5 above), we estimated the probability of detection at Lower Monumental (LMO) and McNary (MCN) Dams using the Cormack-Jolly-Seber single-release model (Cormack 1964; Jolly 1965; Seber 1965).

8) We multiplied the group passing Little Goose Dam on day *i* by the detection and transport probabilities derived from step 7 to estimate numbers in each detection history category. For example, the detection-history category "not detected at Lower Monumental Dam and then bypassed at McNary Dam" would be expressed as

$$(LGO_i) \times [1 - p\ (LMO)] \times [p\ (MCN)] \times [1 - p\ (\text{transport at MCN})].$$

9) We summed the products from step 8 for each day to arrive at the total number of smolts in each detection-history category.

Next we calculated SARs. For a given detection-history category, this was the ratio of the observed number of adults in the category to the estimated number of smolts in that category.

Finally, we estimated the precision of the estimated SARs. This was done using bootstrap methods wherein the individual fish information (i.e., detection history, detection dates, and adult return record) was resampled 1,000 times with replacement (Efron and Tibshirani 1993). Standard errors and confidence limits about the SARs were generated from these bootstrapped estimates.