Transportation of subyearling chinook salmon from McNary Dam: Final report for the 2001 and 2002 juvenile migrations

Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
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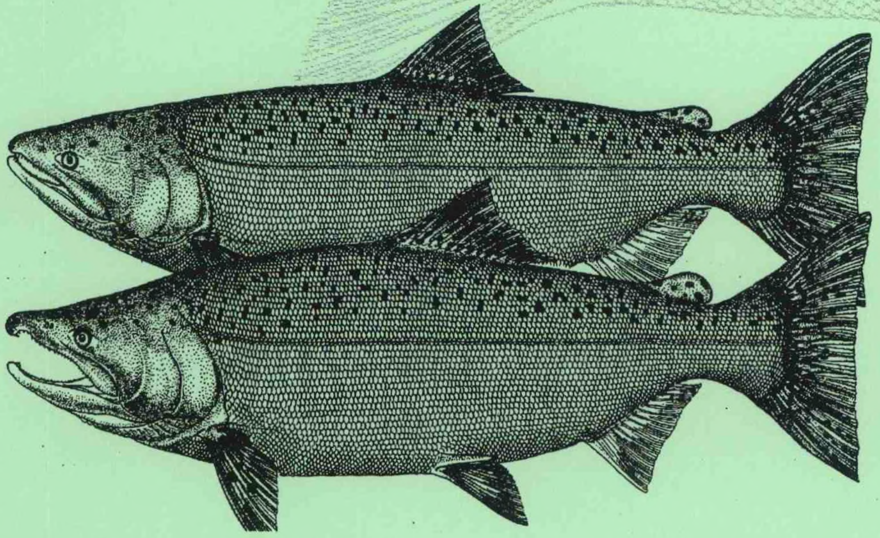
June 2009



Transportation of Subyearling Chinook Salmon from McNary Dam: Final Report for the 2001 and 2002 Juvenile Migrations

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Report of research by

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EXECUTIVE SUMMARY

The National Marine Fisheries Service began studies in 2001 to re-evaluate the efficacy of transportation for subyearling fall Chinook salmon smolts from hydropower projects on the Columbia and Lower Snake Rivers. In 2001 and 2002, we PIT tagged river-run subyearling Chinook salmon at McNary Dam and either released them through the bypass outfall pipe at the dam or loaded them into a barge for transportation. The study was designed to compare the smolt-to-adult return rate (SAR) of fish transported from McNary Dam (T) with the SAR of inriver migrant fish released directly into the tailrace (I), using the ratio T/I.

Subyearling Chinook tagged in 2001. Based on the combined adult returns of subyearling fish PIT-tagged at McNary Dam in 2001 (jacks through age-5-ocean fish), the SAR of transported fish was 0.31% (95% CI, 0.16-0.44%), while the SAR of inriver migrants was 0.31% (95% CI, 0.22-0.38%). These SARs resulted in a geometric mean T/I ratio of 1.22% (95% CI 0.74-2.00%). Conversion rates for these fish (the percentage of adults that successfully migrated from Bonneville Dam to McNary Dam) ranged from 70% for fish released as juveniles into the McNary Dam tailrace to 79% for those transported from McNary Dam. Conversion rates were not adjusted for take in the Zone 6 fishery. Median travel time from Bonneville Dam to McNary Dam was 6 and 7 d, for inriver migrants and transported fish, respectively.

Subyearling Chinook tagged in 2002. Based on the combined adult returns of subyearling fish PIT-tagged at McNary Dam in 2002 (jacks through age-5-ocean fish), the SAR of transported fish was 1.47% (95% CI, 0.56-2.25%), while the SAR of inriver migrants was 1.29% (95% CI, 0.69-1.85%), which resulted in a geometric mean T/I ratio of 1.15% (95% CI 0.85-1.55%). During 2002, we extended the tagging period into August in an attempt to meet the target sample size and also to tag a larger proportion of wild fish that migrate later in summer. Adult returns showed for that both transported and inriver migrant fish, SARs increased for fish tagged as juveniles later in the season. For fish released prior to 26 July, the range of SARs was 0.55-0.66% for transported groups and 0.45-1.19% for inriver groups. Fish tagged on or after 26 July returned at a higher rate than those tagged earlier, with SARs of 1.13-3.01% for transported fish and 1.19-2.35% for inriver migrants.

Conversion rates for fish tagged as subyearlings in 2002 were 69% for transported fish and 71% for inriver migrants (not adjusted for any take in the Zone 6 fishery). Median travel time from Bonneville to McNary Dam was 6 d for both groups.

Migration conditions. River conditions between the two study years were quite different, with low flows, warm water, and low turbidity encountered by inriver migrant smolts during the 2001 drought year. Juvenile survival from McNary Dam tailrace to John Day tailrace averaged 58.1% in 2001 and 74.6% in 2002 (too few fish were detected below John Day Dam to estimate survival to locations further downstream). Travel time from McNary to Bonneville Dam averaged 21.4 d in 2001 and 7.4 d in 2002.

In summary, during 2001, with poor migration conditions and low inriver migrant survival, the geometric mean T/I ratio was 1.22%. In 2002, with favorable migration conditions and high inriver migrant survival, the geometric mean T/I ratio was 1.15%. However, confidence intervals for these estimates were too large to make any definite conclusions. Thus, smolt-to-adult returns from 2001 and 2002 transportation studies at McNary Dam were not appreciably different from those observed by Williams et al. (2005), who concluded there was no evidence that "transportation either harms or helps fall Chinook salmon."

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INTRODUCTION

In 2007, we completed studies at McNary Dam to evaluate transportation of subyearling Chinook salmon *Oncorhynchus tshawytscha* as a means to mitigate for downstream losses that result from migration through the Columbia River federal hydropower system. The primary objective was to compare smolt-to-adult return rates (SARs) between subyearling Chinook salmon transported from McNary Dam and released below Bonneville Dam to those of their cohorts allowed to migrate inriver. Detections from PIT-tagged smolts released to migrate in the river also provided data for short-term survival estimates between the point of release and downstream dams (Muir et al. 2001).

Studies conducted at McNary Dam from 1981 to 1983 concluded that subyearling Chinook salmon that migrate earlier in the summer return as adults in larger numbers than those migrating later in the summer (Giorgi et al. 1994). However, similar evaluations conducted from 1991 to 1994 showed no consistent patterns that would suggest a survival advantage for any portion of the juvenile migration (Tiffan et al. 2000).

Adult return rates for subyearling Chinook salmon smolts PIT tagged in the Snake River in 1994 and transported from McNary Dam were lower than for smolts transported from Snake River dams (Harmon et al. 1996). Even though numbers and percentages of returning adults were low for all groups in 1994, they were considerably lower for fish transported from McNary Dam. This was in spite of the fact that a new, improved bypass and collection facility began operating that year.

Studies conducted in 1995 and 1996 at McNary Dam suggested that subyearling Chinook salmon transported during higher flows (~225,000 ft^3/s) and lower water temperatures (below 18°C) had higher return rates than inriver migrants. Conversely, subyearlings transported under lower flows and higher water temperatures had lower adult return rates than their inriver-migrant cohorts (Williams et al. 2005). These conclusions were contrary to those reported by Harmon et al. (1996), who observed significant transport benefits from McNary Dam, with T/Is from all recovery sites measuring near 3:1 in each of the three years of evaluation.

These varying results were likely influenced by multiple factors, including annual differences in study design, fish stocks collected and tagged at the dam, migration conditions, and ocean conditions, all of which confounded comparisons between years. Between 1999 and 2002, studies were conducted to evaluate the effects of river conditions on inriver migrant survival in the lower Columbia River. Results of these studies showed strong correlations among river conditions including flow, temperature, and turbidity: these correlations make it difficult to determine which variables have the strongest influence on fish survival (Muir et al. 2004; Williams et al. 2005).

New transportation studies were needed to ensure that correct decisions were being made on behalf of listed and non-listed anadromous salmonids of the Columbia River. Several, multi-species transportation studies have been conducted at McNary Dam from the late 1970s through the late 1990s; however, these studies were conducted under conditions that no longer exist. Prior to studies in 2001 and 2002, transportation research using PIT technology (Prentice et al. 1990) had not been conducted from McNary Dam because detection capability for returning adult study fish was lacking in the lower river. However, PIT interrogation systems were scheduled to be installed in the adult ladders at Bonneville and McNary Dams by 2003. Therefore, in summer 2001 we began transport evaluations of subyearling Chinook salmon passing McNary Dam.

Here we report final results from the 2001 and 2002 McNary Dam subyearling Chinook salmon tagging years, which were completed with the recovery of adults in 2006 and 2007.

METHODS

Juvenile Collection and Tagging

Our study design in both 2001 and 2002 used river-run fish captured at McNary Dam utilizing the existing smolt collection facility. The majority of subyearling Chinook salmon collected were upriver brights, originating in the Hanford Reach of the Columbia River and in areas upstream from Priest Rapids Dam (Figure 1). Due to hydroelectric development and other human activities, the majority of subyearling natural production occurs in the 90-km free-flowing Hanford Reach (Dauble and Watson 1997).

Fish were PIT tagged in the McNary Dam wet lab at the smolt collection facility during summer 2001 and 2002. As in past studies, all handling and tagging was conducted using pre-anesthesia techniques (Matthews et al. 1997). After fish were anesthetized, they were gravity-transferred in water into the sorting building. Fish were sorted to remove those that were too small for tagging or showed signs of disease or other conditions that would have reduced post-tagging survival. These subyearling fish appeared generally healthy, with less than 2% of fish collected being rejected for tagging.

After sorting, fish were sent to tagging stations, where each was injected with a PIT tag, measured for fork length, and noted for any unusual body conditions. Tagged fish were placed in pipes that gravity fed to one of two raceways: one for loading into a transport barge, and the other for release into the tailrace through the outfall pipe. Tagged study fish were held an average of 12 h to recover from anesthesia before either release into McNary Dam tailrace or loading for transport.

We sampled the populations collected at McNary Dam at levels to attain relatively consistent numbers of fish for each tagging date. Therefore, the percentage of the daily collection that was handled and tagged for each treatment was dependent upon the number of fish collected at the juvenile fish facility each day.

Numbers of Fish Required for Tagging

In summer 2001, we calculated the number of fish needed for tagging to test the null hypothesis: there is no difference between SARs of subyearling Chinook transported from McNary Dam vs. those that migrated inriver through three additional dams and reservoirs (i.e., T/I = 1). The alternative hypothesis was that SARs for transported fish were at least 30% higher than SARs of inriver migrants (i.e., T/I = 1.3). In the years immediately preceding 2001, SARs to McNary Dam had averaged at least 1.0% for

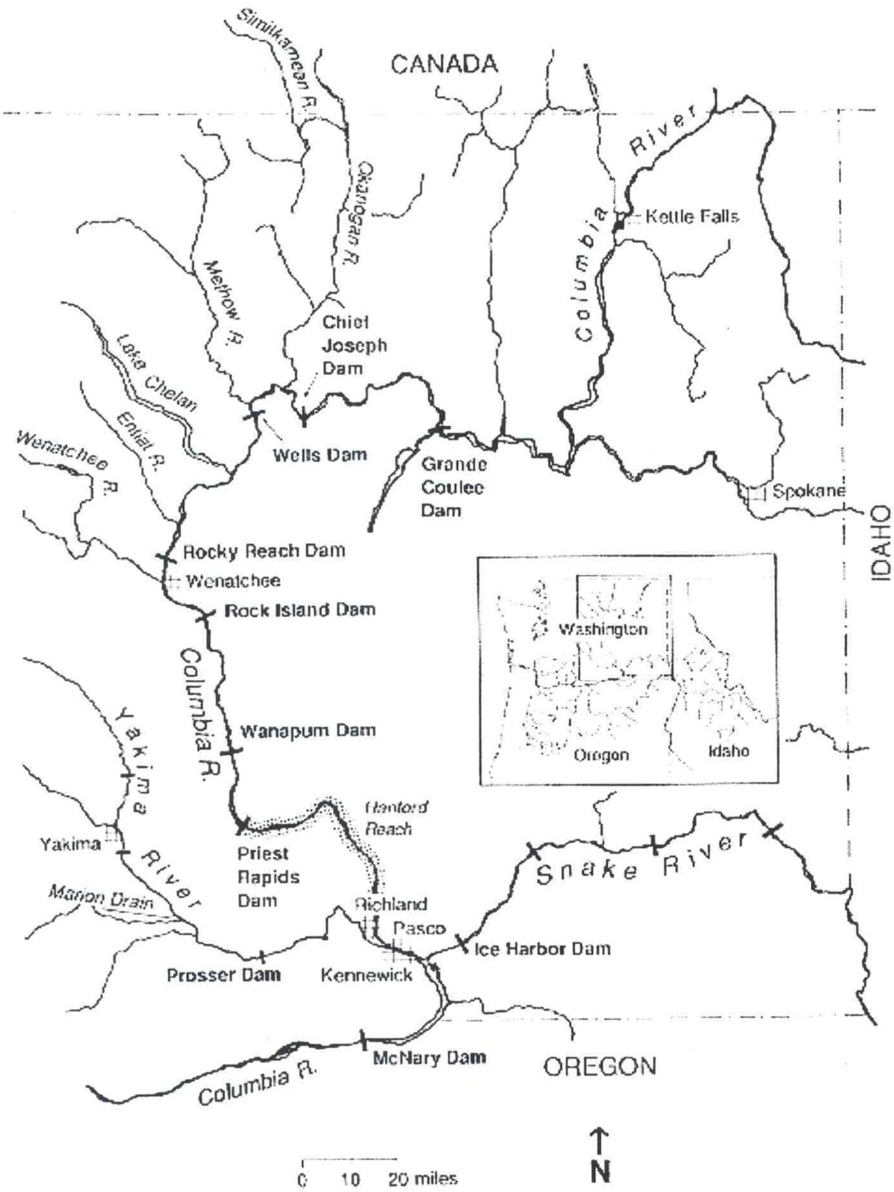

Figure 1. Map of mid-Columbia River Basin, showing principal tributaries and hydroelectric facilities, including McNary Dam.

subyearling Chinook salmon originating from areas above the dam. Therefore, we assumed a minimum SAR of 1.0% for fish transported from McNary Dam in 2001.

The derivations below were based, in part, on the assumption that the true T/I was approximately log-normally distributed. If estimated SARs are lower for transported than for inriver migrant fish, T/I will be between zero and one. Conversely, when SARs estimates are higher for transported than inriver fish, T/I will be greater than or equal to one, thus resulting in a non-symmetric (non-normal) distribution. The log-transformation of T/I values is intended to produce a symmetric distribution.

Additionally, the geometric mean for a set of values was equivalent to the back-transformed arithmetic mean of the log-transformed values. Therefore, we used the geometric mean to estimate overall T/I from replicate "paired" releases, based on the distributional assumption above. We chose the geometric mean estimated T/I rather than the pooled estimate as it incorporated both temporal and sampling components of variability.

Sample-size calculations to obtain transport SARs relative to migrant SARs were based on determining precision around the estimated T/I such that one-half the width of a CI of the true T/I did not contain the value 1. In other words, the CI of the true, natural-log transformed T/I, or LN(T/I), did not contain 0. Therefore, for a given type I error rate ($t_{\alpha/2}$, rejection of a true null hypothesis) and type II error rate (t_{β}, acceptance of a false null hypothesis), the number of fish needed of fish needed was determined in the following manner.

$$\mathrm{LN}\left(\frac{\mathrm{T}}{\mathrm{I}}\right) - \left(t_{\alpha/2} + t_{\beta}\right)\mathrm{SE}\left(\mathrm{LN}\left(\frac{\mathrm{T}}{\mathrm{I}}\right)\right) \approx 0 \tag{1}$$

Using the Delta Method (Burnham et al. 1987),

$$\mathrm{SE}\left(\mathrm{LN}\left(\frac{\mathrm{T}}{\mathrm{I}}\right)\right) \approx \sqrt{\frac{1}{n_T} + \frac{1}{n_I}} = \sqrt{\frac{2}{n}} \tag{2}$$

where n is the number of adult returns per treatment for either n_T, transport, or n_I, in-river groups (with groups set equal to simplify calculation). The previous two statements imply that the sample of adults needed was:

$$n \approx \frac{2\left(t_{\alpha/2} + t_{\beta}\right)^2}{\left(\mathrm{LN}\left(\frac{\mathrm{T}}{\mathrm{I}}\right)\right)^2} \tag{3}$$

We specified $\alpha = 0.05$, $\beta = 0.20$, and an expected transport SAR of at least 1.0%. Sample sizes needed at McNary Dam are listed as follows (where N denotes the number of juveniles):

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

In summer 2002, we calculated the numbers of fish needed for tagging to test the same null hypothesis as in 2001 (T/I = 1). However, we recommended testing a slightly different alternate hypothesis: that SARs were at least 20% higher for subyearling Chinook salmon transported from McNary Dam vs. those that migrated inriver from the tailrace through three additional dams and reservoirs. All other assumptions used to calculate sample sizes remained the same as in 2001.

$$T/I = 1.2$$
$$n = 473$$
$$N_T = 47{,}300$$
$$N_I = (N_T \times T/I) = 56{,}760$$
$$\text{Total juveniles} = 104{,}060$$

Adult Recovery and Data Analysis

Adult PIT-tag detection systems located in the fish ladders of McNary Dam served as the principal recovery sites for adults. Data acquired from other areas were considered ancillary. When adult returns were completed, confidence intervals for the T/Is were calculated using ratios of single-release survival estimates (Burnham et al. 1987) and their associated empirical variances (CIs for daily T/Is and pooled estimates used the estimated sampling variance of Burnham et al. (1987) as noted in Equation 2. The CIs were constructed using the weighted geometric mean, plus or minus the *t*-multiplier (e.g. $t \approx 2.4$ for $\alpha = 0.05$ and 8 release days), all multiplied by the empirical standard error. The weights were inversely proportional to the variance (Muir et al 2001). We also compared the trend in T/Is over time using linear regression with release day and day squared as explanatory variables.

RESULTS

Migration Year 2001

Juvenile Collection and Tagging

We PIT-tagged and released 61,796 river-run subyearling Chinook salmon from 19 June to 27 July 2001 (Table 1). The number of fish tagged daily ranged from 2,451 to 4,991. Of the 61,796 fish released, 23,250 were transported below Bonneville Dam, and 38,546 were released into the tailrace of McNary Dam.

After tagging, fish were allowed to recover for approximately 20 h prior to release. Over the course of the tagging season, we recovered 216 post-tagging mortalities (0.3%). For inriver migrants, average median travel time from McNary to Bonneville Dam was 21.4 d. Median travel time ranged from 15.0 to 34.9 d, depending on release day at McNary Dam (Table 2).

Table 1. Tag date, numbers tagged, and mean fork lengths of fish PIT-tagged and released as part of the McNary subyearling Chinook salmon transportation study, 2001.

	Subyearling Chinook tagged at McNary Dam in 2001		
Date tagged	Number tagged	Number released[a]	Mean fork length (mm)
19 June[b]	4,316	4,274	84.5
21 June	3,043	3,015	88.2
25 June	4,309	4,302	98.8
27 June	4,562	4,548	99.2
29 June	4,069	4,061	98.3
3 July	4,272	4,260	97.8
5 July	2,451	2,435	99.4
9 July	3,352	3,334	98.8
11 July	4,385	4,362	106.8
13 July	4,316	4,309	98.7
17 July	4,864	4,858	91.2
19 July	4,367	4,357	93.0
23 July	4,450	4,443	96.5
25 July	4,991	4,980	96.3
27 July	4,265	4,258	107.7

[a] Release numbers adjusted for duplicates, mortality, and tag loss.

[b] Fish tagged on 19 June were excluded from analysis because all fish on this date were released to migrate inriver and none were transported.

Table 2. Travel time by release day from McNary Dam to Bonneville Dam for migrant fish PIT-tagged and released as part of the McNary Dam subyearling Chinook salmon transportation study, 2001.

Release	Percentile (d)								
day	10th	20th	30th	40th	50th	60th	70th	80th	90th
6/20	9.6	10.0	11.7	13.3	16.5	18.0	20.5	25.1	31.1
6/22	8.8	10.6	11.7	13.6	15.3	17.1	19.5	25.9	42.6
6/26	10.8	12.3	13.7	14.7	18.6	20.3	24.5	34.2	44.9
6/28	10.0	11.9	12.9	17.2	18.5	23.0	32.7	45.3	50.0
6/30	12.4	14.6	16.4	20.5	25.5	31.5	40.4	43.6	45.7
7/04	17.5	25.3	26.9	30.6	34.9	35.7	38.6	40.3	42.9
7/06	15.7	18.2	21.8	27.0	33.5	34.6	36.6	39.8	42.8
7/10	12.7	15.7	18.9	20.1	22.6	25.2	28.0	32.8	34.7
7/12	11.9	15.6	17.3	21.5	26.3	27.8	30.4	31.9	33.6
7/14	10.8	12.8	15.4	16.8	20.7	24.5	26.9	29.5	32.4
7/18	10.2	11.5	12.5	14.7	18.8	21.2	24.5	25.5	26.8
7/20	8.7	9.6	12.3	17.4	18.8	20.6	23.5	23.9	25.8
7/24	9.1	10.5	14.5	16.2	18.4	19.5	21.5	21.8	25.2
7/26	8.5	10.0	11.6	13.7	15.0	17.1	18.4	20.5	22.8
7/28	10.4	11.9	14.1	16.1	16.9	17.8	19.4	21.1	25.0
Mean	11.1	13.4	15.4	18.2	21.4	23.6	27.0	30.7	35.1
SE	0.7	1.1	1.1	1.3	1.6	1.6	1.9	2.2	2.3
95% CI	9.7-12.5	11.1-15.7	13.0-17.8	15.4-21.0	17.9-24.8	20.1-27.0	23.0-31.0	26.1-35.4	30.1-40.1

Adult Recovery and Data Analysis

We began recovering jacks from the 2001 releases at McNary Dam in 2002, and in November 2006 recoveries from 2001 were completed with the collection of age-5-ocean adults. Returns by study group, along with juvenile release numbers are shown in Table 3.

With low total adult returns from 2001 releases, SARs for individual releases were often based on few adults (Table 3). There were no obvious trends in SARs for either transported or inriver migrant fish as the season progressed. SARs ranged from 0.00 to 0.60% for inriver migrant groups and 0.00 to 0.77% for transported groups. The mean SAR of transported fish was 0.31% (95% CI, 0.16-0.44%), while that of inriver migrant fish was 0.31% (95% CI, 0.22-0.38%). For 2001, the pooled T/I ratio was 0.99, with a trend of increasing T/Is with later juvenile release dates (Figure 2). The weighted geometric mean T/I ratio was 1.22 (95% CI, 0.74-2.00), but confidence intervals around these estimates were so wide that no meaningful conclusion could be inferred, and SARs were not significantly different between transported and inriver migrant fish.

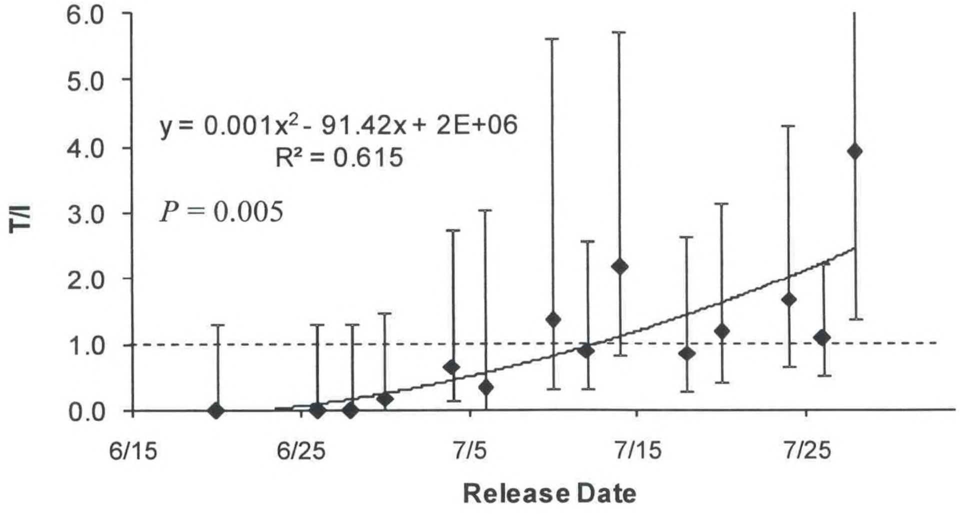

Figure 2. Juvenile subyearling Chinook salmon T/I ratios by release date for river-run fish tagged at McNary Dam as juveniles in 2001.

Table 3. River-run subyearling Chinook salmon returns by release group, with juvenile numbers released, for fish tagged at McNary Dam and released into the tailrace of McNary Dam or transported below Bonneville Dam in 2001.

	Transported			Inriver migrant			Transport/Inriver		
Release date	Release N	Adult N	SAR	Release N	Adult	SAR	Ratio	SE	95% CI
22 Jun	1,200	0[a]	0.00	1,804	0	0.00			
26 Jun	1,817	0[a]	0.00	2,485	7	0.28			
28 Jun	1,919	0[a]	0.00	2,629	10	0.38			
30 Jun	1,664	1	0.06	2,397	8	0.33	0.06[a]	0.06[a]	0.01-0.43[a]
4 Jul	1,826	3	0.16	2,434	6	0.25	0.67	0.47	0.16-2.74
6 Jul	1,055	1	0.09	1,380	4	0.29	0.33	0.37	0.04-3.06
10 Jul	1,409	4	0.28	1,925	4	0.21	1.37	0.96	0.33-5.61
12 Jul	1,854	6	0.32	2,508	9	0.36	0.90	0.47	0.31-2.58
14 Jul	1,807	11	0.61	2,502	7	0.28	2.18	1.05	0.83-5.71
18 Jul	1,897	5	0.26	2,961	9	0.30	0.87	0.48	0.28-2.64
20 Jul	1,615	7	0.43	2,742	10	0.36	1.19	0.58	0.44-3.18
24 Jul	1,653	9	0.54	2,790	9	0.32	1.69	0.79	0.66-4.32
26 Jul	1,836	12	0.65	3,144	19	0.60	1.08	0.40	0.52-2.26
28 Jul	1,698	13	0.77	2,560	5	0.20	3.92	2.06	1.37-11.21
Total	23,250	72	0.31	34,261	107	0.31	0.99	0.15	0.71-1.38
Mean	1,661	5	0.30	2,447	8	0.30	1.22[b]	0.28[b]	0.74-2.00[b]
SE			0.07			0.04			
95% CI	0.16-0.44			0.22-0.38					

[a] Releases from 22-30 June were pooled because no adults returned from juvenile releases on 22, 26, and 28 June 2001.
[b] Weighted geometric mean.

Overall adult conversion rates (not adjusted for Zone 6 fishery) from Bonneville Dam to McNary Dam were 79.0% for transported fish and 70.3% for inriver migrants (Table 4). Conversion rates tended to decline with increasing age class of returning adults.

Median travel time from Bonneville Dam to McNary Dam was 6.0 d for inriver groups and 7.0 d for transport groups. Median travel time varied slightly by age-class, but ranged between 6.0 and 8.0 d (Table 5).

Table 4. Percentage of adult subyearling Chinook salmon PIT-tagged in 2002 that were observed at Bonneville Dam and subsequently detected at McNary Dam (the conversion rate).

	Number seen at Bonneville Dam	Number seen at McNary Dam	Conversion rate (%)
Jacks			
Inriver migrant	19	16	84.2
Transport	8	7	87.5
Age-2-ocean adults			
Inriver migrant	13	12	92.3
Transport	12	11	91.7
Age-3-ocean adults			
Inriver migrant	48	35	72.9
Transport	31	25	80.6
Age-4-ocean adults			
Inriver migrant	51	30	58.8
Transport	28	19	67.9
Age-5-ocean adults			
Inriver migrant	7	4	57.1
Transport	2	2	100.0
Totals			
Inriver migrant	138	97	70.3
Transport	81	64	79.0

Table 5. Travel times from Bonneville Dam to McNary Dam for adult subyearling Chinook salmon PIT-tagged as juveniles in 2001.

Age class	Migration history	Number of adults	Travel time from Bonneville Dam to McNary Dam (d)
Jacks	Inriver migrant	16	6.0
	Transport	7	7.0
Age-2-ocean	Inriver migrant	12	6.0
	Transport	11	7.0
Age-3-ocean	Inriver migrant	35	6.0
	Transport	25	6.0
Age-4-ocean	Inriver migrant	30	6.0
	Transport	19	7.0
Age-5-ocean	Inriver migrant	4	8.0
	Transport	2	7.0
Totals	Inriver migrant	97	6.0
	Transport	64	7.0

Migration Year 2002

Juvenile Collection and Tagging

We were unable to meet our goal of tagging 104,000 fish in 2002 due to low numbers of fish arriving at the dam, a transportation schedule that alternated days, and an unexpected barge breakdown. After the barge breakdown, we had to release fish that had been collected for transportation. For the safety of these fish, we could not continue to hold them for the time required to repair the barge. This resulted in one transport group becoming a migrant group.

We PIT tagged and released 94,972 river-run subyearling Chinook salmon from 20 June to 15 August 2002 (Table 6). The number of fish tagged daily ranged from 1,625 to 4,661. Of the 94,970 fish released, 38,320 were transported and released below Bonneville Dam and 56,650 were released into the tailrace of McNary Dam. We collected 242 post-tagging mortalities (0.3%) during the tagging season.

Table 6. Tag date, release groups, numbers released, and mean fork lengths of fish PIT-tagged and released as part of the McNary Dam subyearling Chinook salmon transportation study, 2002.

	Subyearling Chinook tagged in at McNary Dam in 2002		
Release date	Treatment group	Release number*	Mean fork length (mm)
20 June	Inriver migrant	2,386	100.1
24 June	Inriver migrant	1,801	101.8
26 June	Transport	2,864	98.9
26 June	Inriver migrant	3,207	98.7
28 June	Transport	2,557	100.3
1 July	Transport	1,338	98.9
2 July	Transport	1,151	99.3
2 July	Inriver migrant	2,265	96.7
4 July	Transport	2,575	95.7
4 July	Inriver migrant	3,536	98.2
8 July	Inriver migrant	2,258	95.2
10 July	Transport	2,051	98.9
10 July	Inriver migrant	3,718	95.5
12 July	Transport	2,776	95.8
16 July	Transport	2,645	96.3
17 July	Inriver migrant	3,457	102.1
18 July	Transport	1,625	97.8
18 July	Inriver migrant	2,546	98.5
22 July	Inriver migrant	3,718	95.1
24 July	Inriver migrant	6,036	100.9
26 July	Transport	2,735	99.1
30 July	Transport	3,282	103.4
30 July	Inriver migrant	4,661	106.4
1 August	Transport	1,903	105.5
1 August	Inriver migrant	2,448	108.6
5 August	Inriver migrant	2,886	112.5
7 August	Transport	2,073	110.3
8 August	Inriver migrant	4,269	109.1
9 August	Transport	3,408	110.5
13 August	Transport	2,906	99.4
13 August	Inriver migrant	3,791	98.3
15 August	Transport	2,431	106.7
15 August	Inriver migrant	3,667	104.7

* Release numbers adjusted for mortality and tag loss.

For inriver migrant subyearlings, average median travel time from McNary Dam to Bonneville Dam was 7.4 d. Median travel time ranged from 5.4 to 12.5 d depending on release day at McNary Dam (Table 7). Median travel time to Bonneville Dam was 6.4 d (range 5.4-8.3 d) for fish tagged prior to 26 July and 8.6 d (6.5-12.5 d) for fish tagged after this date.

Table 7. Travel time by release day from McNary Dam to Bonneville Dam for migrant fish PIT-tagged and released as part of the McNary Dam subyearling Chinook salmon transportation study, 2002.

	Percentile (d)								
Release date	10	20	30	40	50	60	70	80	90
20 June	5.0	5.3	5.3	5.7	6.1	6.3	6.5	7.2	9.7
24 June	4.2	4.6	5.1	5.2	5.4	5.5	5.7	6.4	7.4
26 June	4.3	4.4	4.8	5.3	5.4	5.7	6.3	6.5	7.8
2 July	5.1	5.4	6.0	6.5	7.4	9.1	10.5	12.4	14.4
4 July	6.3	6.9	7.3	7.6	8.3	9.3	9.8	10.3	11.7
8 July	5.2	5.4	5.9	6.1	6.3	6.4	6.6	7.4	8.5
10 July	4.8	5.3	5.4	6.0	6.4	6.9	7.3	7.7	9.3
17 July	3.1	3.4	3.4	4.4	5.4	6.8	8.4	9.1	12.4
18 July	5.3	6.3	7.0	7.3	7.7	8.1	8.3	11.4	12.4
22 July	4.5	7.1	7.5	7.5	7.8	8.4	8.6	9.8	19.9
24 July	5.5	5.8	6.0	6.4	6.5	6.8	7.5	8.5	12.5
30 July	5.5	5.7	6.3	6.5	6.5	10.5	12.6	14.4	15.5
1 August	6.2	9.7	11.3	11.6	12.5	12.5	12.6	13.6	14.5
5 August	6.9	7.3	7.9	8.3	8.3	8.4	9.3	10.1	11.8
8 August	5.6	5.6	5.8	6.0	6.6	6.9	7.8	8.4	9.7
13 August	8.5	8.6	8.8	9.5	10.4	11.6	12.4	13.8	17.9
15 August	6.4	7.0	7.5	8.3	9.4	10.1	11.6	14.5	23.9
Mean	5.4	6.1	6.5	6.9	7.4	8.2	8.9	10.1	12.9
SE	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.7	1.1
95% CI	4.8-6.1	5.3-6.9	5.6-7.5	6.0-7.9	6.4-8.4	7.1-9.3	7.8-10.1	8.7-11.5	10.6-15.2

Adult Recoveries and Data Analysis

We began recovering jacks from the 2002 releases at McNary Dam in 2003, and in November 2007, adult returns were completed with the collection of age-5-ocean adults. Returns by study group are shown in Table 8, along with juvenile numbers released.

For fish released in 2002, mean SARs were 1.29% (95% CI, 0.69-1.85%) for inriver migrants and 1.47% (95% CI, 0.56-2.25%) for transported groups. The pooled T/I ratio for 2002 was 1.14, and a trend in the relationship between T/I ratio and juvenile release date was observed, where the T/I ratio was lower in the middle of the season than at either end (Figure 3). The weighted geometric mean T/I ratio was 1.15 (95% CI, 0.85-1.55%), and there was no significant difference between the SARs of transported vs. inriver migrant fish.

We observed that SARs increased for both transported and inriver migrant fish as the season progressed (Table 8). The SARs of fish released prior to 26 July ranged from 0.45 to 1.13% for inriver migrant groups and from 0.55 to 0.66% for transported groups. Fish released on or after 26 July returned at a higher rate, with SARs of inriver migrant fish ranging from 1.19 to 2.35% and those of transported fish from 1.13 to 3.01%.

We also observed differences in return timing for the adults (Figure 4). Fish that were tagged prior to 26 July returned primarily as fall Chinook between August and November, while those tagged later returned as both summer (June to July) and fall Chinook. When compared to known hatchery subyearling fall Chinook that were PIT-tagged and released upstream in the Mid-Columbia, the earlier portion of the migration of river-run fish tagged at McNary Dam in 2002 had the same adult return timing as known hatchery fish.

Overall adult conversion rates (not adjusted for Zone 6 fishery) from Bonneville Dam to McNary Dam were 69.4% for the transported fish and 71.1% for inriver migrants (Table 9). Conversion rates tended to decline with increasing age classes of returning adults.

Overall median travel time from Bonneville Dam to McNary Dam was 6.1 and 6.3 d for inriver and transported groups, respectively (Table 10), with some variation by age class.

Table 8. River-run subyearling Chinook salmon returns by release group, with juvenile numbers released, for fish tagged at McNary Dam and released into the tailrace of McNary Dam or transported below Bonneville Dam in 2002.

	Transported			Inriver migrant				Transport/Inriver			
Release date	Release	Adult	SAR	Release date	Release	Adult	SAR	Release date	T/I	SE	95% CI
26-28 Jun	5,421	36	0.66	20-26 Jun	7,394	33	0.45	20-28 Jun	1.49	0.36	0.92-2.41
1-4 Jul	5,064	28	0.55	2-4 Jul	5,801	38	0.66	1-4 Jul	0.84	0.21	0.51-1.39
10-12 Jul	4,827	31	0.64	8-10 Jul	5,976	46	0.77	08-12 Jul	0.83	0.19	0.53-1.33
16-18 Jul	4,270	24	0.56	17-18 Jul	6,003	68	1.13	16-18 Jul	0.50	0.12	0.31-0.80
26-Jul	2,735	31	1.13	22-24 Jul	9,754	116	1.19	22-26 Jul	0.95	0.19	0.64-1.42
30 Jul-1 Aug	5,185	109	2.10	30 Jul-1 Aug	7,109	155	2.18	30 Jul-1 Aug	0.96	0.12	0.75-1.23
07-9 Aug	5,481	165	3.01	5-8 Aug	7,155	168	2.35	5-9 Aug	1.28	0.14	1.03-1.59
13-15 Aug	5,337	139	2.60	13-15 Aug	7,458	106	1.42	13-15 Aug	1.83	0.23	1.42-2.37
Total	38,320	563	1.47		56,650	730	1.29		1.14	0.06	1.00-1.30
Mean	4,790	70	1.41		7,081	91	1.27	Wt. Geomean	1.15	0.15	0.85-1.55
SE			0.36				0.24				
95% CI			0.56-2.25				0.69-1.85				

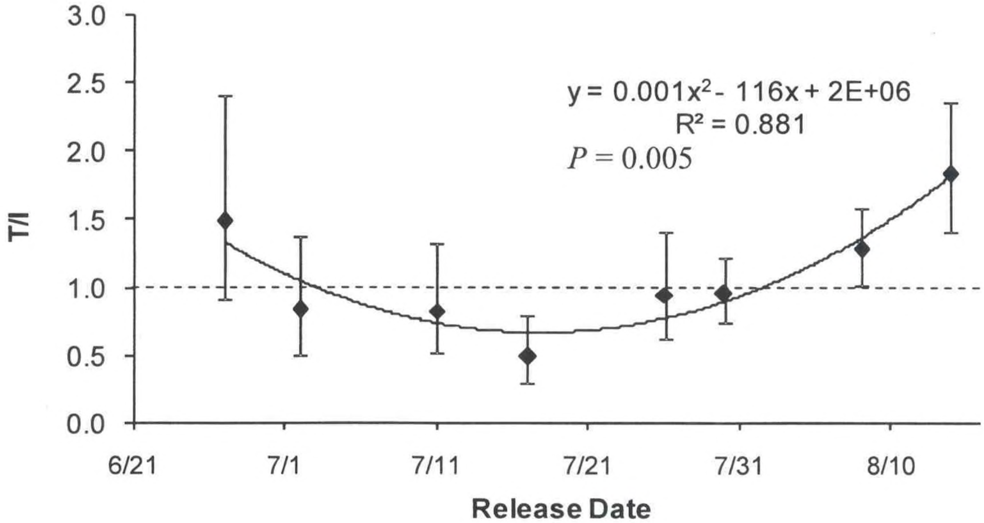

Figure 3. Subyearling Chinook salmon T/I ratios by juvenile release date for river-run fish tagged at McNary Dam as juveniles in 2002.

Table 9. Percentage of adult subyearling Chinook salmon PIT-tagged in 2002 that were observed at Bonneville Dam and subsequently detected at McNary Dam (the conversion rate).

	Number seen at Bonneville Dam	Number seen at McNary Dam	Conversion rate
Jacks			
Inriver migrant	75	62	82.7
Transport	45	34	75.6
Age-2-ocean adults			
Inriver migrant	119	99	83.2
Transport	91	74	81.3
Age-3-ocean adults			
Inriver migrant	338	234	69.2
Transport	250	179	71.6
Age-4-ocean adults			
Inriver migrant	351	233	66.4
Transport	316	203	64.2
Age-5-ocean adults			
Inriver migrant	20	14	70.0
Transport	10	4	40.0
Totals			
Inriver migrant	903	642	71.1
Transport	712	494	69.4

Table 10. Travel times from Bonneville Dam to McNary Dam for adult subyearling Chinook salmon PIT-tagged as juveniles in 2002.

Age class	Migration history	Number of adults	Travel time from Bonneville Dam to McNary Dam (d)
Jacks	Inriver migrant	62	6.2
	Transport	33	6.2
Age-2-ocean	Inriver migrant	99	5.9
	Transport	74	5.9
Age-3-ocean	Inriver migrant	234	5.8
	Transport	179	5.9
Age-4-ocean	Inriver migrant	233	6.9
	Transport	203	6.9
Age-5-ocean	Inriver migrant	14	9.3
	Transport	4	6.9
Totals	Inriver migrant	642	6.1
	Transport	494	6.3

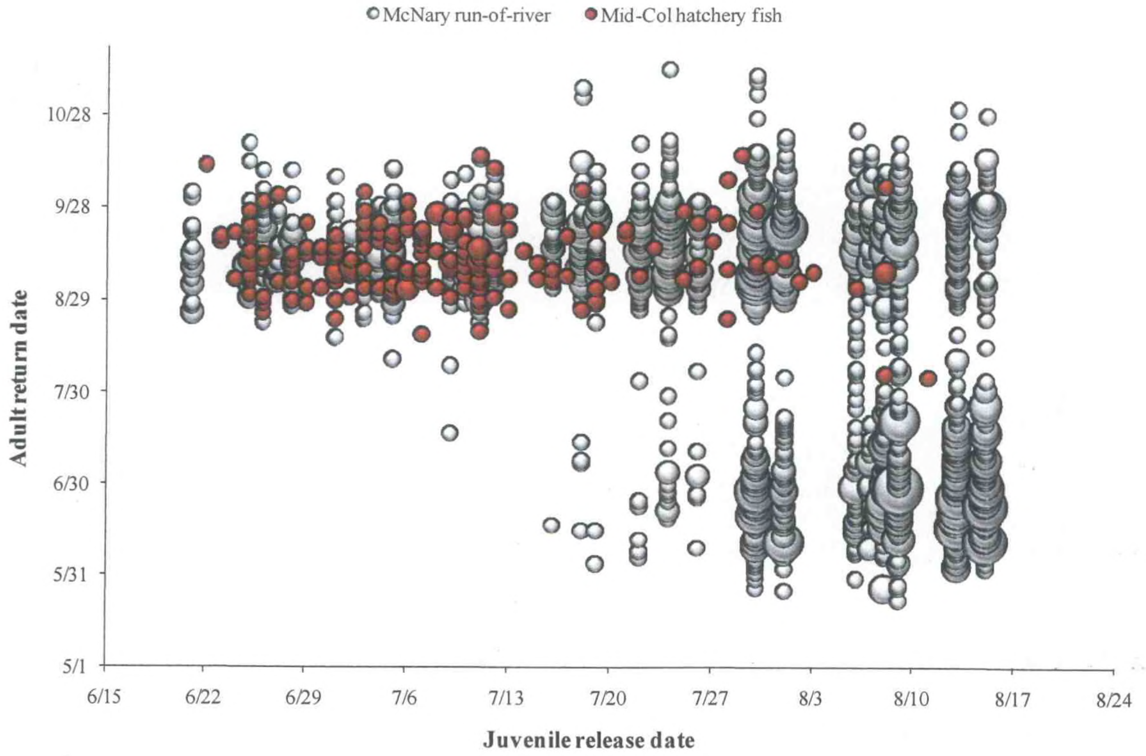

Figure 4. Adult return timing for 2-ocean through 5-ocean river-run subyearling Chinook salmon. Grey bubbles show subyearlings PIT-tagged and released at McNary Dam in 2002, and red bubbles show subyearlings PIT-tagged and released from hatcheries and subsequently detected passing McNary Dam in 2002. Larger bubble sizes indicate higher numbers of fish.

DISCUSSION

Prior to this study, little data existed with which to evaluate the efficacy of transportation from McNary Dam as a means to increase adult returns of subyearling Chinook salmon. Any such evaluation must compare adult returns of transported fish to the alternative of allowing juvenile fish to migrate naturally through the river. In this study, the weighted geometric mean T/I ratio was 1.23 in 2001 and 1.15 in 2002, although no significant difference between SARs was found in either year. Temporal patterns in juvenile migration timing and T/I ratios were also inconclusive in both years. Transported fish had slightly higher SARs than inriver migrants in both years, but confidence intervals were too wide in all cases for a definitive conclusion. While these results were somewhat affected by differences in sample size between the two study years, they were also reflective of important temporal trends and variability in SARs for both groups within and between years.

River conditions were much different between study years, with the 2001 drought year having much lower flows, higher water temperatures, and greater water clarity during summer (Figure 5). Survival from McNary Dam tailrace to John Day tailrace averaged 58.1% in 2001 and 74.6% in 2002 (Muir et al. 2004). In both years, insufficient numbers of fish were detected below John Day Dam for estimates of study fish survival to locations further downstream. Travel time from McNary to Bonneville Dam averaged 21.4 d in 2001 and 7.4 d in 2002.

Smolt-to-adult returns for 2002 treatments groups averaged about 400% of those for the 2001 groups. To some degree, the considerably higher SARs from 2002 may reflected the much better river conditions between McNary and Bonneville Dam. However, conditions downstream from Bonneville Dam, which are faced by both inriver migrants and transported fish, may have been similar in both years. Similar conditions in the estuary and near-shore ocean may have contributed to the similar T/I ratios in both years. The weighted geometric mean T/I in 2001 was 1.22 under poor river conditions and low inriver survival, while the T/I in 2002 was 1.15 under good river conditions and good survival. This evidence weakly supports a benefit to transportation, but again, confidence intervals were too wide to make definite conclusions. Thus the results from 2001 and 2002 were similar to findings of Williams et al. (2005) for transport studies conducted at McNary Dam in 1995 and 1996, and the benefit of transportation for subyearling Chinook salmon remains ambiguous.

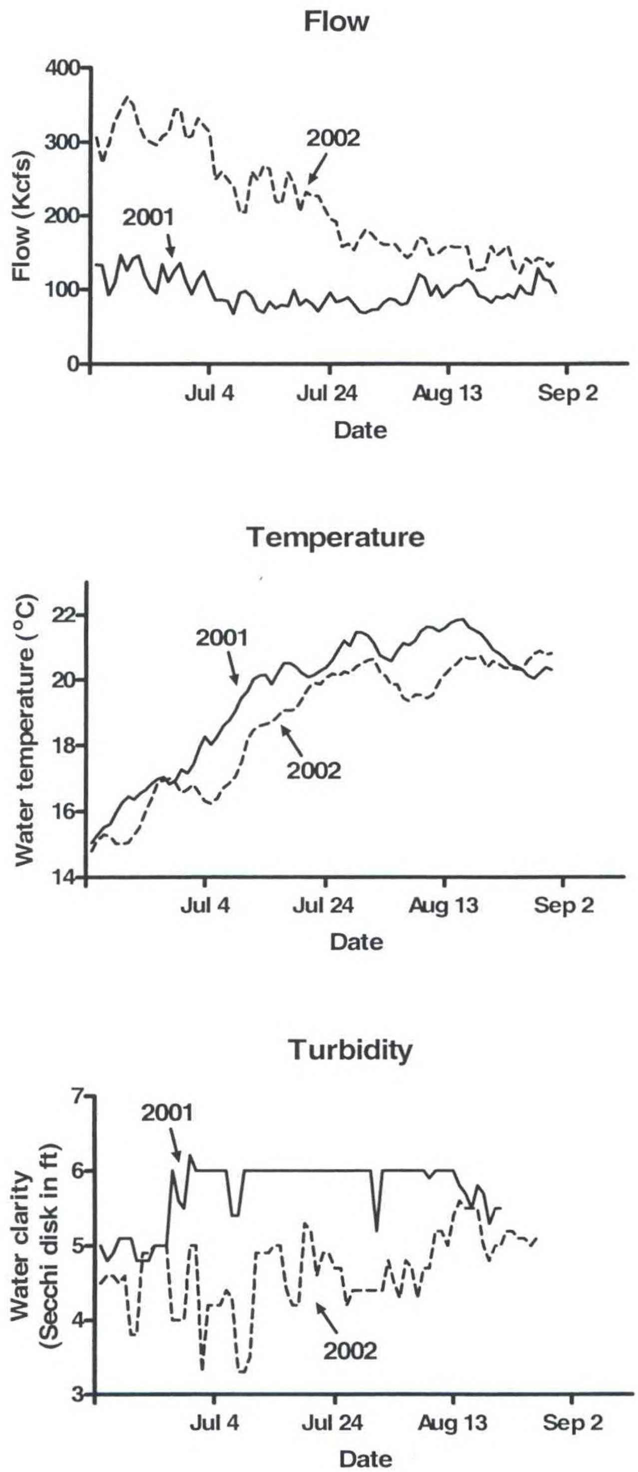

Figure 5. Migration conditions including flow (kcfs), water temperature (°C), and water clarity (Secchi disk reading in ft) at McNary Dam during 2001 and 2002.

River-run subyearling fall Chinook were PIT-tagged and released at McNary Dam in 1999 and 2000 to estimate travel time and downstream survival (Muir et al. 2004; Williams et al. 2005). Results from this study, as well as the present study, provide 4 years of travel time data for subyearling Chinook salmon (1999-2002). Despite these data, we lack sufficient information to make definitive statements regarding the potentially complex dynamics among travel time, survival, and environmental conditions in the 123-km reach between McNary and John Day dams.

Travel times for subyearling Chinook salmon are largely dependent on water velocity, with the largest effect observed when low flows increase. Slower travel time most likely affects survival by prolonging or shortening exposure to predators in John Day reservoir. However, there is not a defined flow/survival relationship sufficient to identify flow requirements necessary to achieve consistent results (Tiffen et al. 2000).

Subyearling Chinook salmon rear during the downstream migration, growing at rates of nearly 1.0 mm/d (Connor et al. 2003; Bottom et al. 2005). Based on this growth rate and our observed median downstream travel times from McNary to Bonneville Dam, inriver migrant growth during the study would have been 15.0-34.9 mm in 2001 and 5.4-12.5 mm in 2002. Thus, inriver migrant subyearlings arriving below Bonneville Dam may have grown enough so that their loss to predators below Bonneville Dam was lower that of transported cohorts, which had less time to grow. If predation below Bonneville Dam is higher for smaller transported fish and lower for larger inriver migrants, this would in part account for the lack of transport benefit we observed. This higher rate of predation on transported fish could have occurred even though survival from McNary to Bonneville Dam tailrace was poor for subyearlings compared to yearling inriver migrants.

Muir et al. (2006) hypothesized that for spring/summer Chinook, length differences between fish transported from Lower Granite Dam and their inriver migrant cohorts increased the vulnerability of transported fish to piscivorous predators. They speculated that predation downstream from Bonneville Dam after release from barges resulted in increased post-Bonneville Dam mortality, or *D*, for transported fish. The distance and travel time to Bonneville Dam are much greater for yearling Chinook from Lower Granite (461 km and 2-4 weeks) than for subyearlings from McNary Dam (236 km and 1-3 weeks). However, the higher growth rates observed for subyearlings migrating in summer, and higher predation rates during summer (Vigg et al. 1991) might result in similar or greater losses to predation for transported vs. inriver migrant subyearlings.

Of fish released as juveniles in 2002, those exhibiting the highest SARs were tagged on or after 26 July. These fish were slightly larger at the time of their juvenile migration, and were collected from a combination of varying run types arriving at McNary Dam. The Columbia River drainage is populated with Chinook salmon possessing high diversity in juvenile migrational behavior and timing.

In both the mid-Columbia and Snake Rivers, spring-run Chinook salmon produce stream-type juveniles, and fall-run Chinook salmon produce predominantly ocean-type juveniles. However, the so-called "summer-run" adult Chinook produce ocean-type juveniles in the mid-Columbia River above McNary Dam and stream-type juveniles in the Snake River (Matthews and Waples 1991). Thus in the Snake and Columbia Rivers, the summer run is a mix of late-migrating stream-type Chinook from the upper tributaries and early migrating ocean-type Chinook from the lower tributary and mainstem areas.

The inclusion of summer-run Chinook salmon boosted adult return numbers significantly. Juvenile summer-run Chinook have been found to migrate sooner than juvenile spring Chinook in the Snake River (Achord et al. 1996). However, it appears that fall Chinook pass McNary Dam prior to summer-run Chinook salmon, with known hatchery origin fish migrating sooner than wild populations.

As expected, conversion rates from Bonneville Dam to McNary Dam tended to be lower in general for fall Chinook than for spring/summer Chinook. This was due to the higher harvest rate in the Zone 6 harvest area for fall Chinook salmon.

In summary, the SARs from our 2001 and 2002 releases at McNary Dam supported the conclusion of Williams et al. (2005) for Snake River subyearling fall Chinook salmon: “no empirical evidence exists to suggest that transportation either harms or helps fall Chinook salmon."

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REFERENCES

Achord, S. A., G. M. Matthews, O. W. Johnson, and D. M. Marsh. 1996. Use of passive integrated transponder (PIT) tags to monitor migration timing of Snake River Chinook Salmon smolts. North American Journal of Fisheries Management 16:302-313.

Bottom, D. L., C. A. Simenstad, J. Burke, A. M. Baptista, D. A. Jay, K. K. Jones, E. Casillas, M. H. Schiewe. 2005. Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-68, 246 p.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society, Monograph 5. Bethesda, Maryland.

Connor, W. P., R. K. Steinhorst, and H. L. Burge. 2003. Migrational behavior and seaward movement of wild subyearling fall Chinook salmon in the Snake River. North American Journal of Fisheries Management 23:414-430.

Dauble, D. D., and D. G. Watson. 1997. Status of fall Chinook salmon populations in the mid-Columbia River, 1948-1992. North American Journal of Fisheries Management 17:283-300.

Giorgi, A. E., D. R. Miller, and B. P. Sandford. 1994. Migratory characteristics of juvenile ocean-type chinook salmon, Oncorhynchus tshawytscha, in John Day Reservoir on the Columbia River. Fishery Bulletin 92:872-879.

Harmon, J. R., N. N. Paasch, K. W. McIntyre, K. L. Thomas, B. P. Sandford, and G. M. Matthews. 1996. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1994. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Matthews, G. M., N. N. Paasch, S. Achord, K. W. McIntyre, and J. R. Harmon. 1997. A technique to minimize the adverse effects associated with handling and marking salmonid smolts. Progressive Fish Culturist 59:307-309.

Matthews, G. M., R. S. Waples. 1991. Status Review for Snake River Spring and Summer Chinook Salmon. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-F/NWC-200.

Muir, W. D., R. A. McNatt, G. A. Axel, S. G. Smith, D. M. Marsh, and J. G. Williams. 2004. Survival of subyearling fall Chinook salmon in the free-flowing Snake River and lower Snake River reservoirs, 2003, and from McNary Dam tailrace to John Day Dam tailrace in the Columbia River, 1999-2002. Report of the National Marine Fisheries Service to Bonneville Power Administration, Portland Oregon, Contract No. 00004922, Project 1993-029-00.

Muir, W. D., S. G. Smith, J. G. Williams, E. E. Hockersmith, and J. R. Skalski. 2001. Survival estimates for migrant yearling Chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and lower Columbia Rivers, 1993-1998. North American Journal of Fisheries Management 21:269-282.

Muir, W. D., D. M. Marsh, B. Sandford, S. G. Smith, and J. G. Williams. 2006. Post-hydropower system delayed mortality of transported Snake River stream-type Chinook salmon: unraveling the mystery. Transactions of the American Fisheries Society 135:1523–1534.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Tiffan, T. F., D. W. Rondorf, and P. G. Wagner. 2000. Physiological development and migratory behavior of subyearling fall Chinook salmon in the Columbia River. North American Journal of Fisheries Management 20:28-40.

Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Williams, J. G., S. G. Smith, R. W. Zabel, W. D. Muir, M. D. Scheuerell, B. P. Sandford, D. M. Marsh, R. McNatt, and S. Achord. 2005. Effects of the federal Columbia River power system on salmon populations. NOAA Technical Memorandum NMFS-NWFSC-63.