Technical Report 2007-1

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

EVALUATION OF FISHWAY MODIFICATIONS TO IMPROVE PASSAGE OF ADULT CHINOOK SALMON AND STEELHEAD THROUGH THE TRANSITION POOL AT LOWER GRANITE DAM, 2006

A report for Project ADS-00-2

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U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho, Moscow, Idaho 83844-1141

And

B. J. Burke
National Marine Fisheries Service
2725 Montlake Blvd. East, Seattle, Washington 98112

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U.S. Army Corps of Engineers
Portland and Walla Walla Districts

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Acknowledgements

Many people provided their time and assistance during the course of this study. K. Tolotti, T. Dick, and D. Joosten installed and maintained radiotelemetry equipment. E. Johnson, T. Dick, S. Lee, M. Morasch, and D. Joosten helped with field operations and data collection and D. Joosten interpreted and summarized the telemetry data at the University of Idaho. Funding for this study was provided by the U.S. Army Corps of Engineers, Walla Walla District. We also thank D. Fryer and S. Milligan, U.S. Army Corps of Engineers, for their cooperation and assistance during all phases of this project.

Abstract

Previous studies of Pacific salmonid passage over Snake River dams indicated slowed passage at transition pools in adult fishways. In 2001 and 2002, we conducted an experiment to determine if modified weirs affected adult salmon and steelhead passage times and route selection through the Lower Granite Dam transition pool. Attraction flows through weir orifices were experimentally manipulated using removable aluminum panels. Results from these studies indicated a greater proportion of radio-tagged spring–summer Chinook salmon passed straight through the transition pool when the panels were deployed, and mean transition pool passage times were significantly lower. Based on these results, the U.S. Army Corps of Engineers modified the fish ladder at Lower Granite Dam in 2006. Modifications included narrowing the junction pool walls and increasing the weir crest height of the lower eleven weirs. To evaluate the effectiveness of the modifications, we radio-tagged and monitored adult spring–summer and fall Chinook salmon and steelhead as they passed Little Goose and Lower Granite dams and compared their performance to that measured during previous years without modifications in place. Transition pool passage times at Lower Granite Dam for spring–summer Chinook were significantly faster in 2006 than in 2003 and 2004 (non-modified years) and the other runs exhibited similar, though not statistically different responses. The frequency of downstream exits out of the transition pool back to the collection channel or tailrace for spring-summer Chinook salmon at Lower Granite Dam in 2006 were lower than in 2003 and 2004. We also compared the relative passage times by individual fish at Little Goose and Lower Granite dams in an effort to statistically control for interannual variation river environment. For all runs, we found that passage time was relatively faster at Lower Granite Dam compared to Little Goose Dam in 2006 versus 2003 and 2004. While the results generally support the hypothesis that the weir modifications improved passage and provide no evidence that the modifications worsened passage conditions, we caution that rigorous conclusions can not be made because behaviors were made for only one year post-modification and inter-annual variability in pool passage times can be high.

Introduction

In early 2006, the Army Corps of Engineers (Walla Walla District) modified the fish ladder at Lower Granite Dam in an attempt to increase the number of adult salmonids swimming directly through the transition pool and thereby reducing transition pool passage times. Previously fluctuations in tailwater elevations at Lower Granite Dam resulted in the lower weirs of the fish ladder being submerged during high tailwater elevations. When the lower weirs are submerged velocities through the underwater orifices are decreased in turn reducing attraction flows for adult salmon and steelhead. In 2001 and 2002, experimental ladder modifications were tested to determine if temporary modifications increased under water orifice velocities and fish passage times. The 2006 modifications were based on results from the prototype weir modification that was tested in 2001 and 2002. During the treatment condition in 2001 and 2002, aluminum panels were inserted into the transition pool (at the two most downstream weirs) in order to increase water velocities through submerged orifice. Results from these studies indicated a greater proportion of radio-tagged spring and summer Chinook salmon passed straight through the transition pool and mean transition pool passage times were significantly lower during the treatment condition (Naughton et al. 2006 and 2007). To evaluate the effectiveness of the permanent modification design we monitored radio-tagged adult Spring-summer Chinook salmon, steelhead and fall Chinook salmon as they passed Lower Granite Dam, and compared their performance to that measured during previous years without modifications in place. Integral to this evaluation was to monitor passage of these same fish at Little Goose Dam as a means to account for interannual variation in passage conditions between study years.

Methods

Fishway Modification

The modification consisted of narrowing the width of the junction pool walls from 38 ft to 20 ft near a 90 degree turn in the fishway just downstream from the transition pool (Figure 1). Additionally, the eleven most downstream weirs were modified with aluminum/steel plating to increase the height of weir crest by approximately 3.2 ft to increase the depth of each weir pool, increasing hydraulic head, and thereby increase water velocities through the weir orifices. Increased orifice velocity is thought to facilitate attraction and entrance by adult salmonids. We evaluated tailwater elevations recorded at Lower Granite dam (obtained from http://www.nwd-wc.usace.army.mil/tmt/) in order to determine when and how many weirs were submerged before and after the 2006 weir modification.

Tagging and Monitoring

We radio-tagged 242 spring–summer Chinook salmon, 285 fall Chinook salmon, and 300 steelhead at Ice Harbor Dam from 3 May through 30 October 2006. No adult salmon or steelhead were tagged from 13 July through 28 August because of regulations restricting the handling of adult fish during periods of high water temperatures (≥ 22.2 ºC or 72 ºF). Four regurgitated tags were found (one in the transportation tank and three at the release site) and one mortality at the release site was reported. For detailed descriptions of tagging methods see Naughton et al. (2006) and Mann and Peery (2005). In addition to our tagging effort at Ice Harbor Dam, we radio-tagged 380 adult spring–summer Chinook salmon at Bonneville Dam as part of other study objectives. Adult migrants tagged at Bonneville Dam that were recorded at Little Goose or Lower Granite dams were included in our analyses. Preliminary analyses provided no evidence of significant differences in transition pool passage time among fish released at the two sites at either dam.

A) B)

Figure 1. A) Narrowing of the junction pool wall and B) aluminum/steel plating on lower eleven weirs in the fish ladder at Lower Granite Dam during 2006.

Passage time analyses included only first ascents, i.e., we excluded passage attempts after fallback events. However, we did calculate the fallback percentage (the number of unique fish with transmitters that fell back divided by the number of unique fish with transmitters known to have passed the dam) and the fallback rate (the number of fallback events divided by the number of unique fish known to have passed the dam) for both Little Goose and Lower Granite dams.

We monitored movements of radio-tagged fish with fixed radio telemetry sites at Little Goose and Lower Granite dams (Figure 2). We used SRX/DSP receivers/processors (Lotek Wireless) connected to nine-element aerial Yagi and underwater antennas to determine when a fish first reached the tailrace, approached a fishway entrance, entered a fishway, moved within a fishway, and/or exited a fishway. Seven underwater antennas at Lower Granite Dam and six underwater antennas at Little Goose Dam were used to detect when fish first entered the transition pool and exited the transition pool. Telemetry data were downloaded from receivers every 1-2 weeks. Outages at transition pool receivers occurred on a total of nine days (four days in July and five days in October) at Little Goose Dam and six days in October at Lower Granite Dam in 2006.

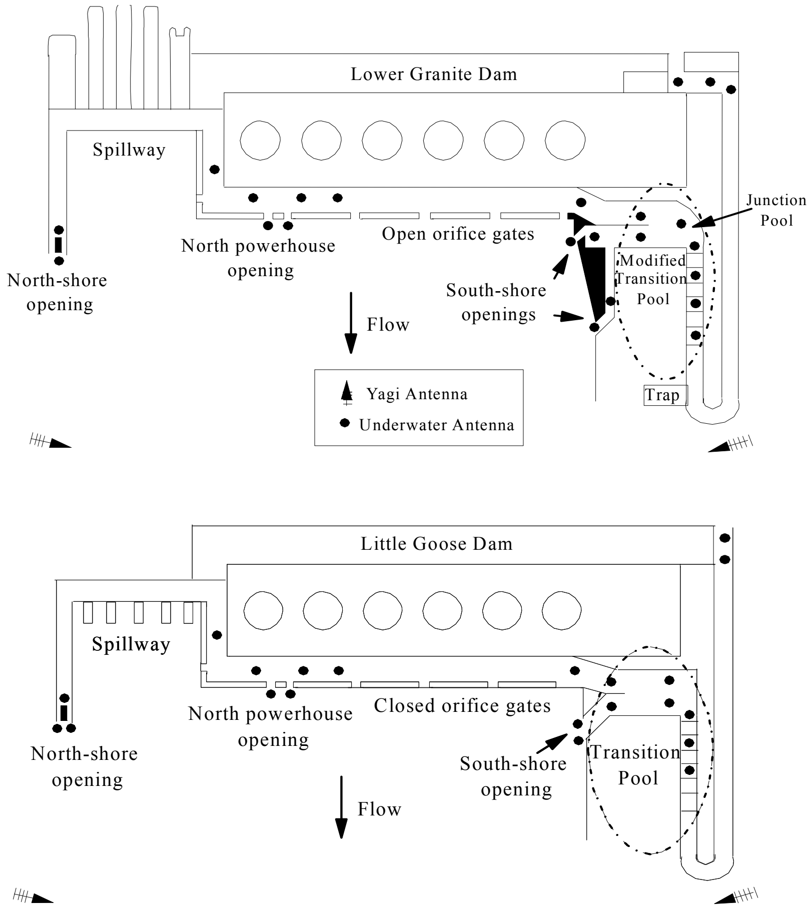

Figure 2. Aerial view of radio antenna locations at Little Goose (lower panel) and Lower Granite dams (upper panel) during 2006. Tailrace aerial antennas are approximately 1 km downstream from face of the dams.

Passage Times and Fish Behaviors

We calculated six passage time metrics for radio-tagged salmon and steelhead at both Little Goose and Lower Granite dams. Specifically, we calculated the time fish used to swim: (1) from the first tailrace record to first approach at the dam, (2) from the first tailrace record to first entry at the dam, (3) from first approach to first fishway entry, (4) from first entry to first record in the transition pool (5) from first record in transition pool to last record in transition pool, and (6) from first tailrace record to last record at top-of-the-ladder. We also classified passage routes into one of three categories for each fish: (1) fish that swam straight through the transition pool, (2) fish that exited the transition pool into the collection channel or (3) fish that exited the transition pool into the tailrace. We also evaluated transition pool passage times as they related to overnighting behavior. Specifically, we compared pool passage times for tagged fish that did or did not pass the transition pool on the same day as their first detection in the transition pool. We also tested for an association between overnighting and temperature gradients in the fish ladder (Caudill et al. 2006). We matched the forebay and tailrace hourly temperatures to the time a fish first entered the transition pool (FP) to determine temperature differences for overnighting behavior.

Statistical Analysis

We used analysis of variance (ANOVA) to test whether transition pool passage times in 2006 (modified weirs) were significantly different from 2003 and/or 2004 (years without modifications). Transition pool passage times were natural log transformed to normalize the data. Tukey's multiple comparison test (Zar 1999) was used to determine which years differed significantly from each other when overall ANOVA results were significant. We also used an ANOVA to test if tailrace water temperatures were significantly different among years (2003, 2004, and 2006) for each run (based on the hourly tailrace temperature when a fish first entered the transition pool). Among those fish with complete migration histories at both dams we calculated the difference in passage time at the two dams as (Transition Pool Passage $\text{Time}_{\text{Lower Granite}}$) - (Transition Pool Passage $\text{Time}_{\text{LittleGoose}}$). We then tested (Kruskal-Wallis) whether there was a significant difference between the distributions of passage time differences among years to ask whether relatively "fast" fish at Little Goose were also fast Lower Granite before and/or after the modification.

Results

Tailwater Elevations

During 2006, average monthly tailwater elevations in the fish ladder (based on hourly tailwater elevation data plus 1.5 ft) ranged from 634.6 ft (above mean sea level) in July to 638.5 ft in November (Figure 3). In April and May 2006, fish ladder water elevations were relatively high compared to previous years (Figure 3). However, there were only four days in May when the most downstream weir (634 ft) was submerged (Table 1).

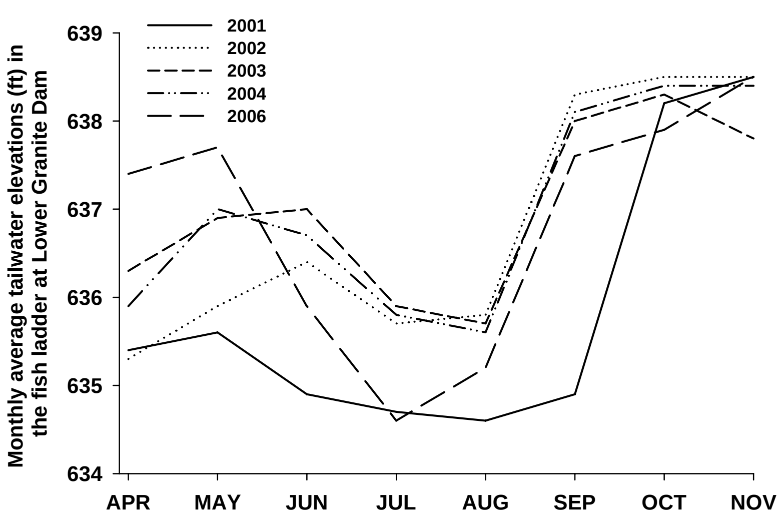

Figure 3. Monthly average tailwater elevations (ft above sea level) at the most downstream weir (634 ft) in the fish ladder at Lower Granite Dam in 2001-2004, and 2006.

Table 1. Number of days in each month the two most downstream weirs (634 and 635 ft above sea level, respectively) were submerged at Lower Granite Dam in 2001-2004, and 2006. Note: The elevation of weir submergence was estimated as the fish ladder elevation (1.5 ft higher than tailwater elevation) plus 2 ft in 2001-2004 and tailrace plus 5.2 ft in 2006 post-modification.

	Month	2001	2002	2003	2004	2006
Weir 1	April	5	4	20	9	
	May	5	13	28	31	4
	June		25	26	21	
	July		2	7	1	
	August	1	6			
	September	1	26	30	30	
	October	28	29	31	31	
	November	29	27	27	30	
Weir 2	April	4	1	3	1	
	May		3	10	13	
	June		2	13	12	
	July			1		
	August					
	September		25	27	27	
	October	24	29	31	31	
	November	29	27	23	30	

Passage and behavior

Of the 242 spring-summer Chinook radio-tagged at Ice Harbor Dam in 2006, 177 (73 %) were recorded at Little Goose Dam and 155 (64%) were recorded at Lower Granite Dam. Of the 285 radio-tagged fall Chinook salmon in 2006, 232 (81%) were recorded at Little Goose Dam and 221 (78%) were recorded at Lower Granite Dam. Of the 300 radio-tagged steelhead, 258 (86%) and 250 (83%) were recorded at Little Goose and Lower Granite dams in 2006, respectively. An additional 108 and 102 spring–summer Chinook salmon radio-tagged at Bonneville Dam in 2006 were recorded at Little Goose and Lower Granite dams, respectively. A total of 245 (144 tagged at Bonneville Dam and 101 tagged at Ice Harbor Dam) spring–summer Chinook salmon, 203 fall Chinook salmon, and 237 steelhead were recorded in the transition pool at Lower Granite Dam during 2006.

Fallback percentages ranged from 1.9-8.0% in 2006. At Little Goose Dam, 6.2% of radio-tagged spring-summer Chinook (6.6 % fallback rate), 1.9 % of fall Chinook and 4.0 % of steelhead (4.4 % fallback rate) fell back at the dam in 2006. At Lower Granite Dam, 8.0% of radio-tagged spring-summer Chinook (10.0 % fallback rate), 3.0 % of fall Chinook (4.0 % fallback rate) and 3.0 % of steelhead fell back at the dam in 2006.

Spring–summer Chinook salmon tagged at Ice Harbor and Bonneville dams had generally similar median passage times at Little Goose and Lower Granite dams (Table 2). In terms of relative, rather than any absolute, differences, the most notable exception was the median times for spring–summer Chinook salmon to make a first entry after first approach.

Table 2. Sample sizes and median time (hours) from first tailrace record to first approach, first tailrace record to first entry, first approach to first entry, first entrance to first record in a transition pool (first pool), first pool to last record in the transition pool (last pool) prior to making last ascent of fishway, and total time to pass at Little Goose and Lower Granite dams for adult spring–summer Chinook (SPSUCK) salmon, fall Chinook salmon (FACK), and steelhead (STHD) radio-tagged at Ice Harbor and Bonneville dams during 2006.

	Release sites									
	Bonneville SPSUCK		Ice Harbor SPSUCK		All SPSUCK		Ice Harbor FACK		Ice Harbor STHD	
	n	Med.	n	Med.	n	Med.	n	Med.	n	Med.
First tailrace to first approach										
Little Goose	97	**1.4**	148	**1.3**	245	**1.4**	135	**0.9**	194	**1.4**
Lower Granite	98	**1.3**	139	**1.3**	237	**1.3**	114	**1.1**	168	**1.6**
First tailrace to first entry										
Little Goose	88	**9.2**	146	**8.0**	234	**8.2**	132	**1.5**	177	**2.5**
Lower Granite	88	**4.7**	121	**3.3**	209	**3.8**	96	**2.1**	138	**3.8**
First approach to first entry										
Little Goose	96	**4.6**	164	**3.6**	260	**3.7**	221	**0.5**	223	**0.6**
Lower Granite	91	**1.9**	128	**0.6**	219	**1.1**	168	**0.4**	200	**0.7**
First entry to first pool										
Little Goose	96	**0.3**	162	**0.2**	258	**0.3**	218	**0.01**	223	**0.11**
Lower Granite	91	**0.8**	128	**0.7**	219	**0.7**	166	**0.31**	198	**0.21**
First pool to last pool										
Little Goose	96	**0.20**	141	**0.29**	237	**0.27**	136	**5.45**	151	**1.13**
Lower Granite	101	**0.43**	144	**0.66**	245	**0.56**	203	**2.90**	237	**0.80**
First tailrace to ladder top										
Little Goose	93	**18.9**	138	**21.1**	231	**20.7**	129	**13.8**	199	**13.0**
Lower Granite	95	**15.3**	137	**14.6**	232	**14.8**	100	**16.9**	158	**16.4**

Median times from first entry to first pool for fall Chinook salmon and steelhead ranged from 13-19 minutes at Lower Granite Dam compared to less than three minutes for both species at Little Goose Dam (Table 2). These differences were probably explained by the majority of fall Chinook salmon using the south shore entrance near the transition pool at Little Goose Dam, but not at Lower Granite Dam (63% of tagged fall Chinook salmon and 54% of tagged steelhead first entering Little Goose Dam at the south shore entrance [proximal to the transition pool] and 60% of fall Chinook and 61% of steelhead entering Lower Granite Dam at the north entrances [on the opposite side of the dam from the transition pool; Figure 1]). Median pool passage times ranged from 3.7% to 17.1% of median dam passage times among runs at Lower Granite Dam.

For spring–summer Chinook salmon, transition pool passage times at Lower Granite Dam were significantly lower in 2006 than in 2003 and 2004 (P<0.001; Figure 4). Transition pool passage times at Lower Granite Dam for spring–summer Chinook salmon tagged at Bonneville and Ice Harbor during 2006 were not significantly different (P=0.763). For fall Chinook salmon and steelhead at Lower Granite Dam, we found no significant difference in pool passage times among years (P=0.627 for fall Chinook salmon and P=0.132 for steelhead; Figure 4). Median transition pool passage times were lower in 2006 than in 2003 and 2004 for all runs but not as low as times reported during the prototype weir modification in 2001 and 2002 (Table 3).

In comparing differences in transition pool passage times of individual fish at Little Goose and Lower Granite dams, we found a significant difference among years for spring–summer Chinook salmon,(P<0.001), fall Chinook salmon (P=0.010), and steelhead (P=0.047). These results indicate a decrease in the difference in median transition pool passage times between the two dams in 2006 compared to previous years (2003 and 2004; Figure 5).

The proportion of fish passing straight through the transition pool at Lower Granite Dam was variable, with the values observed in 2006 falling within the range observed in previous years (Table 5). A higher proportion of fish from all runs passed straight through the transition pool at Little Goose compared to Lower Granite; however, median transition pool passage times for fish that passed straight through were lower at Lower Granite than at Little Goose Dam (Table 4). Differences in the proportions of spring-summer Chinook salmon may account for the significantly lower pool passage time at Lower Granite Dam in 2006 compared to 2003 and 2004 (Table 3). In contrast, while a higher percentage of steelhead swam straight through the transition pool in 2006 than in 2003, we found no significant differences in pool passage times for steelhead among years. Fall Chinook salmon showed relatively little variation in percentages that swam straight through the transition pool (< 5% difference among years; Table 5) and there was no significant difference in pool passage times among years.

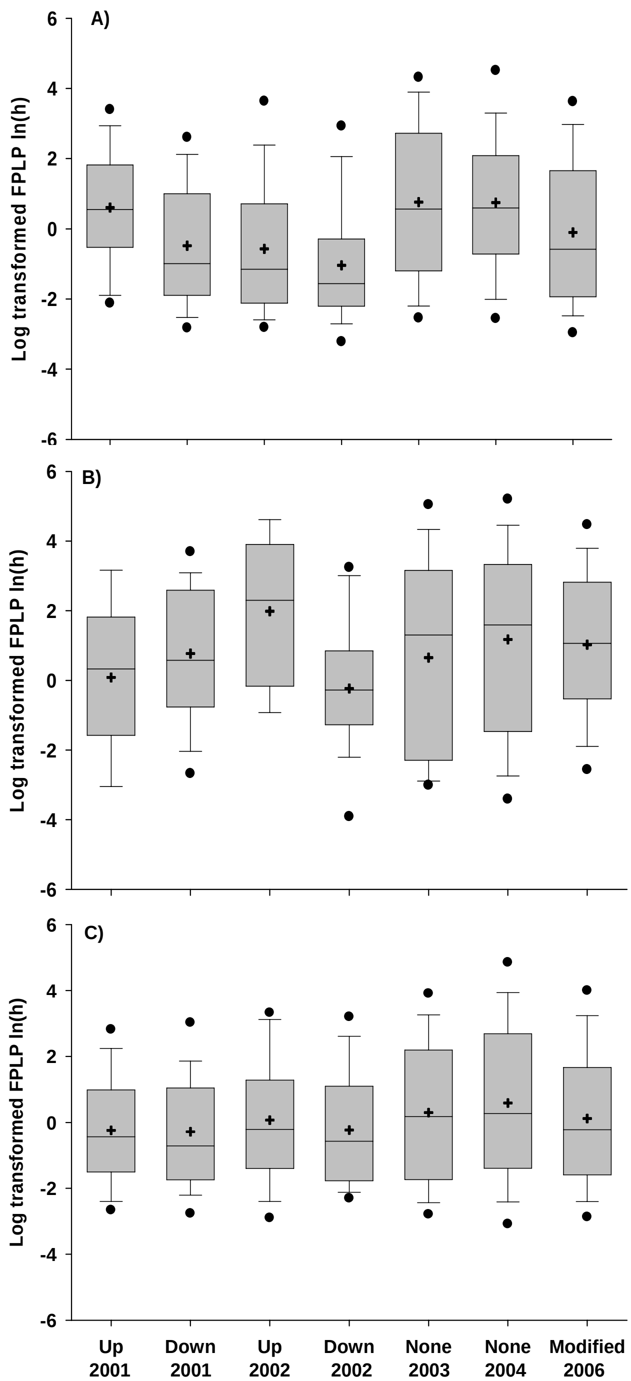

Figure 4. Means (crosses), medians (horizontal lines within boxes), quartiles (upper and lower bounds of boxes), 10th and 90th percentiles (ends of whiskers), and 5th and 95th percentiles (circles) of the natural log transformed transition pool passage times (FPLP) at Lower Granite Dam for A) spring–summer Chinook salmon, B) fall Chinook salmon, and C) steelhead in 2001-2004 and 2006. Up position of the weir panels was during the control period and down position of the weir panels was during the weir modification treatment while testing the prototype weir modification in 2001-2002. See Table 2 for sample sizes.

Table 3. Median time for radio-tagged adult spring–summer Chinook salmon, fall Chinook salmon, and steelhead to swim through the transition pools (TP) at Little Goose and Lower Granite dams during 2000-2004, and 2006

Species	Year	Treatment condition	Little Goose Median TP time (h)	Little Goose n	Lower Granite Median TP time (h)	Lower Granite n
Spring-summer Chinook	2000	Control	0.91	229	0.42	39
	2000	Treatment[1]	-	-	0.60	154
	2001	Control	1.83	508	1.73	209
		Treatment[2]	-	-	0.37	209
	2002	Control	0.24	239	0.32	114
		Treatment[2]	-	-	0.21	146
	2003	None	0.20	309	1.75	309
	2004	None	0.36	181	1.80	184
	2006	Modified	0.27	237	0.56	245
Fall Chinook	2000	Treatment[1]	5.98	28	3.91	25
	2001	Control	4.29	59	1.60	18
		Treatment[2]	-	-	1.78	37
	2002	Control	2.81	50	12.02	12
		Treatment[2]	-	-	0.76	19
	2003	None	1.31	38	3.68	27
	2004	None	2.14	44	4.92	51
	2006	Modified	5.45	136	2.90	203
Steelhead	1994	None	-	-	0.49	194
	1996	None	-	-	0.88	177
	2000	Treatment[1]	0.75	360	0.26	319
	2001	Control	2.06	220	0.65	80
		Treatment[2]	-	-	0.49	93
	2002	Control	1.12	500	0.81	170
		Treatment[2]	-	-	0.57	174
	2003	None	0.26	231	1.19	207
	2004	None	0.50	148	1.20	151
	2006	Modified	1.13	151	0.80	237

[1]- After initial weir modification structure was in place and weir panels were added at Lower Granite Dam.
[2] - Weirs in ‘down’ position simulated modifications made to Lower Granite weirs for 2006.

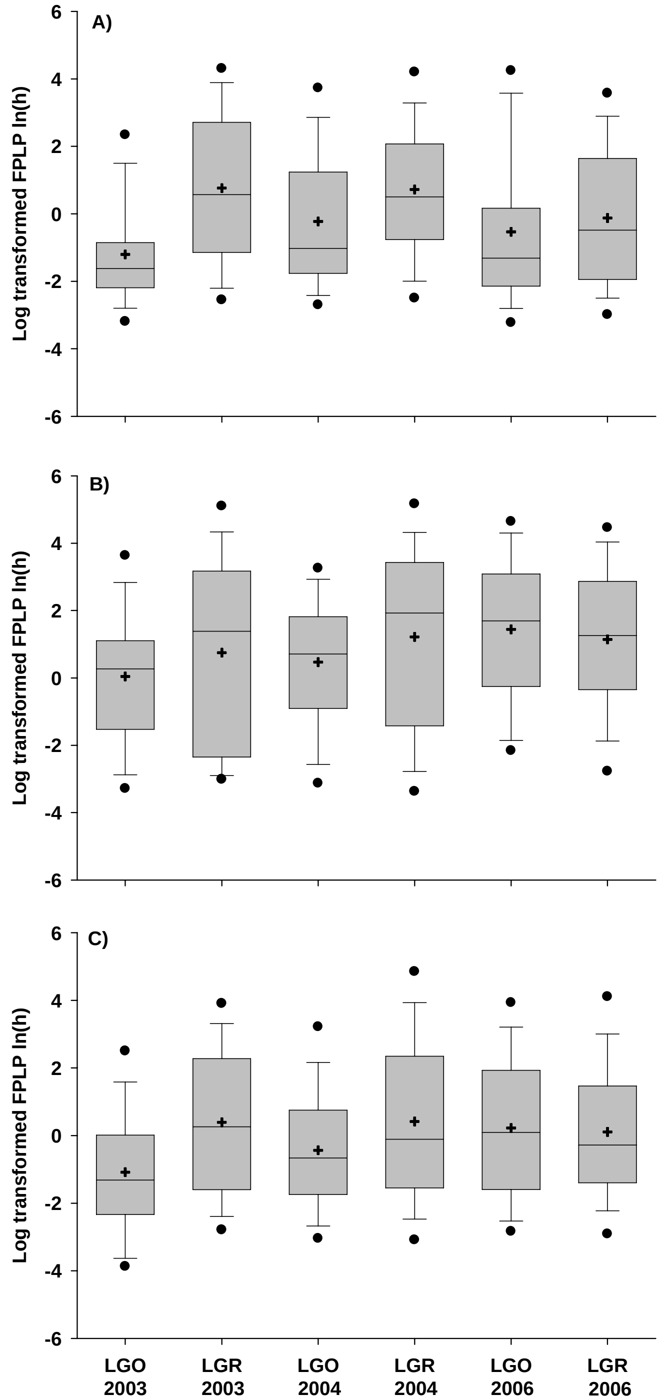

Figure 5. Means (crosses within boxes), medians (horizontal lines within boxes), quartiles (upper and lower bounds of boxes), 10th and 90th percentiles (ends of whiskers), and 5th and 95th percentiles (circles) of the natural log transformed transition pool passage times at Little Goose and Lower Granite dams for A) spring–summer Chinook salmon, B) fall Chinook salmon, and C) steelhead in 2003-2004 and 2006.

Table 4. Median time in hours for radio-tagged adult spring–summer Chinook salmon (SPSU CK), fall Chinook salmon (Fall CK), and steelhead (STHD) to swim through the transition pools at Little Goose (LGO) and Lower Granite (LGR) dams based on behaviors exhibited during 2006. The proportions of fish exhibiting each transition pool behavior are shown in parentheses.

Species	Dam	n	Straight through	Exit pool but not dam	Exit dam	All behaviors
SPSU CK	LGR	245	0.10 (0.30)	0.53 (0.39)	10.30 (0.31)	0.56 (1.00)
SPSU CK	LGO	237	0.12 (0.47)	0.45 (0.30)	24.24 (0.23)	0.27 (1.00)
Fall CK	LGR	203	0.10 (0.11)	0.63 (0.27)	10.06 (0.62)	2.90 (1.00)
Fall CK	LGO	136	0.17 (0.18)	0.72 (0.12)	12.28 (0.70)	5.45 (1.00)
STHD	LGR	237	0.16 (0.35)	0.60 (0.23)	6.41 (0.42)	0.80 (1.00)
STHD	LGO	148	0.17 (0.38)	0.89 (0.13)	7.29 (0.49)	1.13 (1.00)

Overnighting and Temperature

We used tailrace temperatures as surrogates for pool temperatures and found significantly higher temperatures experienced by radio-tagged spring–summer Chinook salmon ($P<0.001$) in 2006 than in 2003 and 2004 (Figure 6). Radio-tagged fall Chinook salmon experienced significantly ($P=0.001$) warmer tailrace temperatures in 2003 than in 2004 or 2006. Radio-tagged steelhead experienced significantly ($P<0.001$) warmer tailrace temperatures in 2003 and 2004 than in 2006.

Differences in temperature between the top and bottom of fish ladders appear to slow migration at Snake River Dams (Caudill et al. 2006). Mean differences between hourly forebay and tailrace temperatures were slightly higher for all runs of radio-tagged fish that overnighted at Lower Granite Dam than those that did not, though mean temperature differences were smallest in 2006 (Table 6). All radio-tagged fish that did not pass the dam on the same day as their initial detection at the dam had longer transition pool passage times.

Table 5. Percentage of radio-tagged Chinook salmon and steelhead passing straight through the transition pool, exiting the transition pool but not the dam and exiting the dam to the tailrace at Lower Granite Dam in 2001-2004, and 2006. Sample sizes are in parentheses.

Species	Year	Weirs	n	Straight through	Exit pool but not dam	Exit dam
Spring-summer chinook	2001	Control	209	10.1 (21)	43.1 (90)	47.9 (98)
	2001	Treatment	208	36.5 (76)	29.3 (61)	34.1 (71)
	2002	Control	114	36.8 (42)	49.1 (56)	14.0 (16)
	2002	Treatment	146	53.4 (78)	37.0 (54)	9.6 (14)
	2003	None	309	19.4 (60)	31.4 (97)	49.2 (152)
	2004	None	184	16.3 (30)	34.2 (63)	49.5 (91)
	2006	Modified	245	29.4 (72)	38.8 (95)	31.8 (78)
Fall chinook	2001	Control	18	33.3 (6)	55.6 (10)	11.1 (2)
	2001	Treatment	37	37.8 (14)	40.5 (15)	21.6 (8)
	2002	Control	7	0.0	85.7 (6)	14.3 (1)
	2002	Treatment	24	25.0 (6)	50.0 (12)	25.0 (6)
	2003	None	27	25.9 (7)	14.8 (4)	59.3 (16)
	2004	None	51	29.4 (15)	9.8 (5)	60.8 (31)
	2006	Modified	205	11.2 (23)	26.8 (55)	62.0 (127)
Steelhead	2001	Control	80	48.8 (39)	40.0 (32)	11.3 (9)
	2001	Treatment	93	49.5 (46)	39.8 (37)	10.8 (10)
	2002	Control	170	32.4 (55)	54.1 (92)	13.5 (23)
	2002	Treatment	174	44.3 (77)	46.0 (80)	9.8 (17)
	2003	None	207	32.4 (67)	25.6 (53)	42.0 (87)
	2004	None	151	37.7 (57)	17.9 (27)	44.4 (67)
	2006	Modified	237	35.4 (84)	22.4 (53)	42.2 (100)

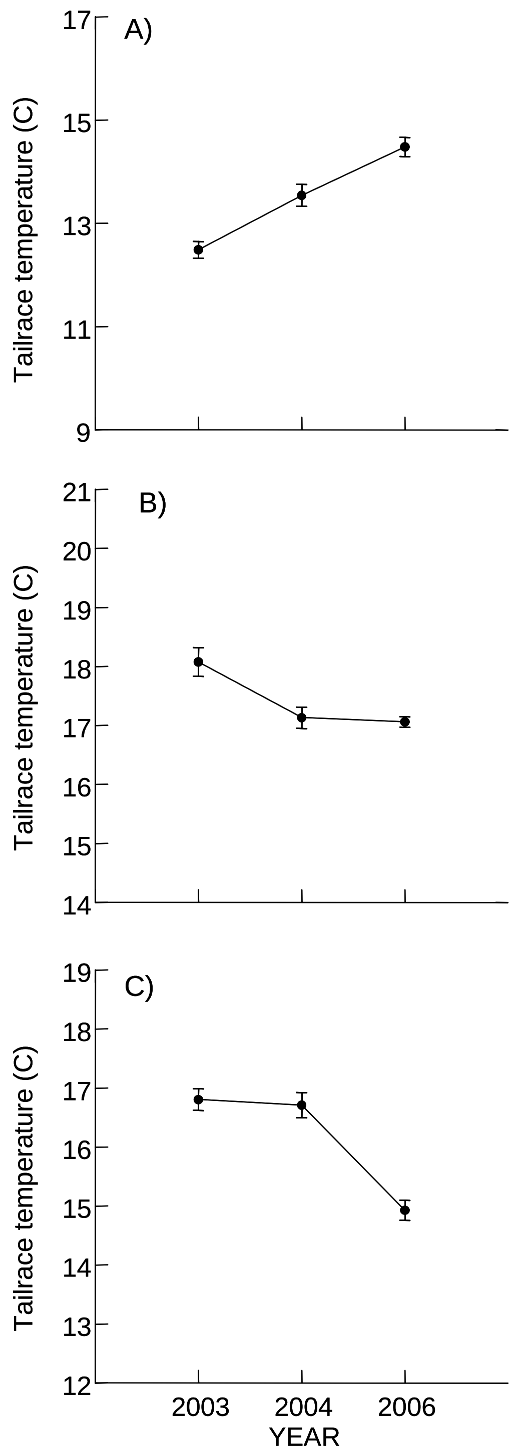

Figure 6. Least square means of tailrace temperatures with standard error bars for A) spring–summer Chinook, B) fall Chinook salmon, and C) steelhead in 2003-2004, and 2006. Note temperature scales are different.

Table 6. Number of radio-tagged Chinook salmon and steelhead overnighting at Lower Granite Dam, mean temperature difference between the forebay and tailrace temperature, and the median transition pool passage time (FPLP). Percent of fish shown in parentheses. *Note temperature data were not available for all fall Chinook and steelhead in 2006; therefore only fish with temperature data are shown.

Year	Species	Overnight	n	Mean temperature difference (C)	Range of temperature difference (C)	Median FPLP (h)
2003	Spring-summer	Yes	92 (30)	0.57	-0.11 - 5.06	34.50
		No	217 (70)	0.27	-0.07 - 3.79	0.57
	Fall	Yes	7 (26)	1.24	0.36 - 1.70	58.11
		No	20 (74)	0.70	0.05 - 2.28	0.59
	Steelhead	Yes	52 (25)	0.60	0.06 - 6.01	21.28
		No	155 (75)	0.33	-0.20 - 1.70	0.58
2004	Spring-summer	Yes	40 (22)	0.97	-0.04 - 3.74	26.13
		No	144 (78)	0.46	-0.13 - 3.74	0.95
	Fall	Yes	24 (47)	1.14	0.14 - 4.25	28.29
		No	27 (53)	0.94	0.01 - 2.60	0.25
	Steelhead	Yes	42 (28)	1.00	-0.02 - 4.99	31.48
		No	109 (72)	0.73	-0.03 - 3.22	0.46
2006	Spring-summer	Yes	47 (19)	-0.13	-0.40 - 0.10	20.72
		No	198 (81)	-0.10	-0.40 - 0.31	0.33
	Fall*	Yes	33 (41)	0.57	0.17 - 0.99	26.90
		No	47 (59)	0.50	0.17 - 0.99	1.24
	Steelhead*	Yes	8 (19)	0.56	0.17 - 0.99	23.95
		No	34 (81)	0.52	-0.14 - 0.99	0.75

Discussion

We compared passage behavior in 2006 after the transition pool at Lower Granite Dam was modified to previous data. Such analyses are clearly useful, though rigorous conclusions about the effects of the transition pool on passage behavior are potentially confounded by interannual variability in other factors influencing passage behavior. Therefore, we also looked at the relative change in passage time between Little Goose Dam and Lower Granite Dam to account for interannual variability. This approach provides some control for interannual differences in environmental conditions (e.g., Figure 6). Specifically, if the modification was successful, the times at Lower Granite Dam should have become relatively faster. Indeed, comparisons of interannual differences in passage times at the two dams revealed that passage times were faster at Lower Granite Dam in 2006 (fall Chinook salmon and steelhead), or that difference between passage time decreased (spring-summer Chinook salmon).

Transition pool passage times at Lower Granite Dam for spring-summer Chinook were significantly faster in 2006 than in 2003 and 2004 and fall Chinook and steelhead exhibited similar, though not statistically different responses. Faster transition pool passage times for spring–summer Chinook salmon could be partly attributed to the higher temperatures in 2006 than in 2003 and 2004 rather than the modifications *per se*. We have observed radio-tagged fish migrating faster during warmer temperatures up to a threshold of approximately 20 ºC (Keefer et al. 2004). Rates of overnighting during 2006 were the lowest of three study years in spring-summer Chinook salmon, supporting the hypothesis that the modification reduced overnighting rates in this run. However, ladder temperature differences are associated with overnighting (Caudill et al. 2006), and the average ladder temperature difference during 2006 was the lowest during the three years. In other runs, overnighting rates in 2006 were within the range observed in previous years and thus did not appear to be strongly associated with the weir modification or water temperature differences in the ladder at Lower Granite Dam. Warmer water temperatures at the tops of ladders compared to tailraces may induce fish to spend the night at the dam and contribute to slower transition pool passage times (Caudill et al. 2006), though observed temperature differences in 2006 were lower than in previous years.

Weir modifications appeared related to a reduction of the frequency of downstream exits out of the transition pool back to the collection channel or tailrace for spring-summer Chinook salmon at Lower Granite Dam in 2006 compared to 2003 and 2004; however, this pattern was not evident for the other two runs. Moreover, the percentage of fish passing straight through the transition pool was also lower for all runs in 2006 compared to treatment periods during the experimental modification in 2001 and 2002. The shorter transition pool passage times and lower number of transition pool exits during the treatment periods in 2001 and 2002 were probably the result of increased flow at underwater weir orifices during treatment compared to control periods (Naughton et al. 2006). Unfortunately, data on weir head differences and velocities measured in the transition pool in 2006 were not available to us, so comparison of orifice flow velocities among years was not possible.

Median transition pool passage times were not lower at Little Goose Dam in 2006 compared to 2003 and 2004 as they were at Lower Granite Dam, suggesting the lower median transition pool passage times at Lower Granite Dam during 2006 were at least partially due to the ladder modifications. We additionally observed a decrease in the difference in individual transition pool passage times between Lower Granite and Little Goose dams in 2006 compared to 2003 and 2004 which is consistent with the weir modifications aiding transition pool passage. However, sample sizes for fall Chinook and steelhead transition pool records were about one-third smaller at Little Goose Dam than Lower Granite during 2006 due to receiver outages.

Conclusions

Results from the 2006 evaluation indicated that the modifications decreased pool passage times for spring–summer Chinook salmon but not for fall Chinook salmon or steelhead based on our inter-year comparisons. Importantly, we found no evidence to suggest the modifications impeded the passage of radio-tagged adult salmonids. Nonetheless, we believe the results should be viewed with caution because the modifications were evaluated for only one year and inter-annual variability in pool passage times can be high, nor could we adequately control for the effects of interannual variation in river conditions on passage time.

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